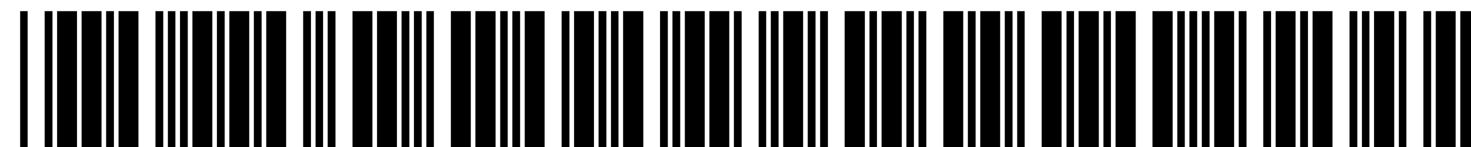
US009214446B2

(12) **United States Patent**
Yoda

(10) **Patent No.: US 9,214,446 B2**
(45) **Date of Patent: Dec. 15, 2015**

(54) **METHOD OF MANUFACTURING OPTICAL MODULE**

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(73) Assignee: **CITIZEN HOLDINGS CO., LTD.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 667 days.

(21) Appl. No.: **13/422,656**

(22) Filed: **Mar. 16, 2012**

(65) **Prior Publication Data**

US 2012/0234458 A1 Sep. 20, 2012

(30) **Foreign Application Priority Data**

Mar. 18, 2011 (JP) 2011-060916

(51) **Int. Cl.**
B29C 65/00 (2006.01)
H01L 23/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 24/83*** (2013.01); *H01L 24/32* (2013.01); *H01L 2224/29019* (2013.01); *H01L 2224/2919* (2013.01); *H01L 2224/29111* (2013.01); *H01L 2224/32059* (2013.01); *H01L 2224/32238* (2013.01); *H01L 2224/7592* (2013.01); *H01L 2224/81192* (2013.01); *H01L 2224/81444* (2013.01); *H01L 2224/81895* (2013.01); *H01L 2224/83099* (2013.01); *H01L 2224/83193* (2013.01); *H01L 2224/83208* (2013.01); *H01L 2224/83385* (2013.01); *H01L 2224/83444* (2013.01); *H01L 2224/83895* (2013.01); *H01L 2924/014* (2013.01); *H01L 2924/01005* (2013.01); *H01L 2924/01006* (2013.01); *H01L 2924/01023* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B29C 66/92; B29C 66/924; B29C 66/95; B29C 66/952; Y10T 156/1039; H01L 2224/29111; H01L 2924/01079; H01L 2924/00014; H01L 2224/2919; H01L 2924/0132; H01L 2924/0105
USPC 156/64, 219, 295, 358; 385/80; 438/31
See application file for complete search history.

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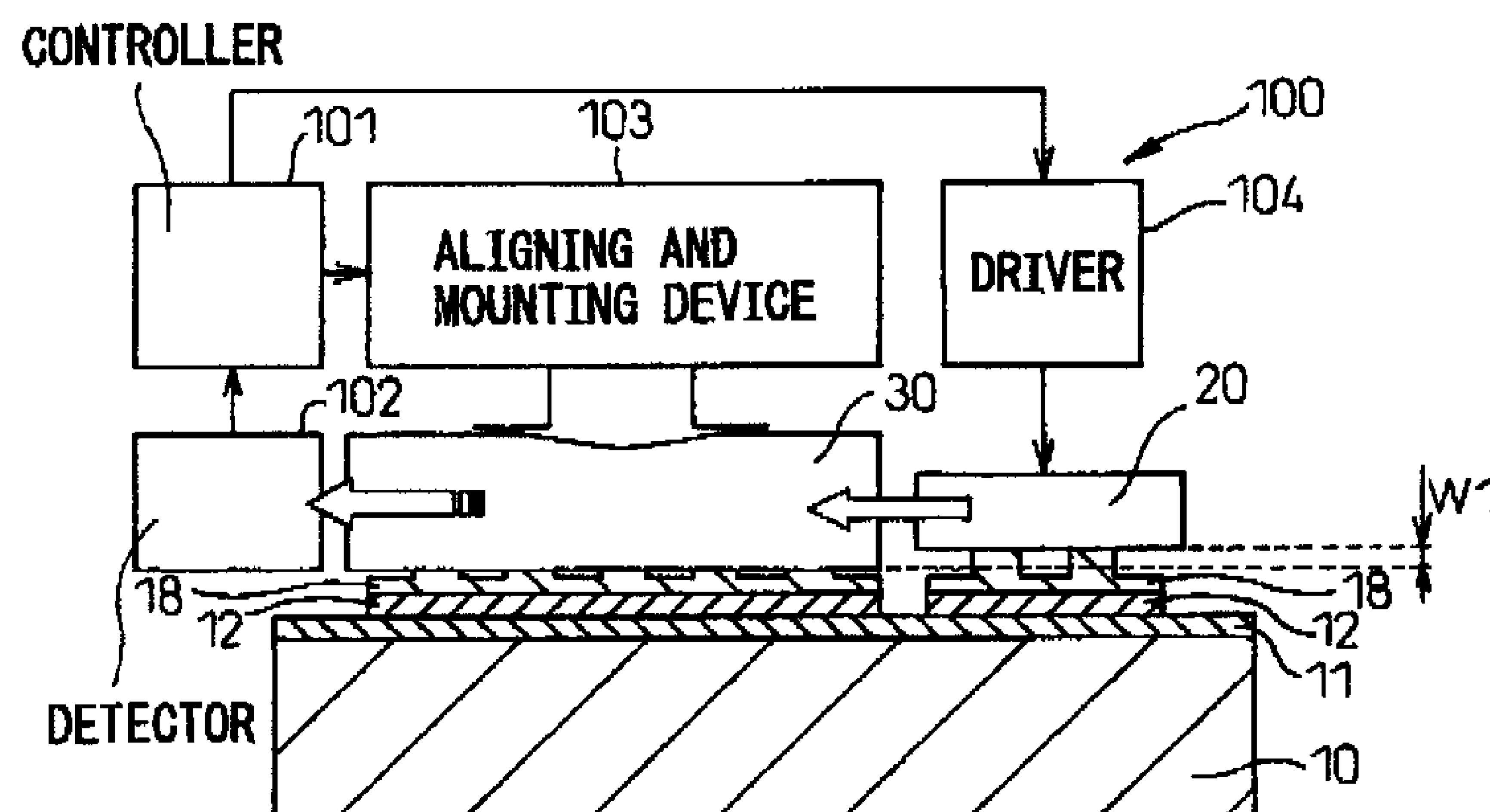
Primary Examiner — George Koch
(74) *Attorney, Agent, or Firm* — Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P.

(57) **ABSTRACT**

The present invention is directed to provide a method of manufacturing an optical module in which optical devices are optically aligned with high precision regardless of elastic return of bonding bumps. The invention provides a method of manufacturing an optical module including the steps of forming bumps for bonding made of metal on a substrate, and bonding a second optical device on the bonding bumps by applying a load so that the bumps for bonding are deformed only by a predetermined amount from a position where a first optical device and the second optical device are optically coupled most efficiently and, after that, releasing the load.

4 Claims, 14 Drawing Sheets



(52) **U.S. Cl.**
CPC *H01L 2924/01029* (2013.01); *H01L 2924/0132* (2013.01); *H01L 2924/01033* (2013.01); *H01L 2924/01075* (2013.01); *H01L 2924/01079* (2013.01); *Y10T 156/1039* (2015.01)

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Chang, Shyh-Ming et al., "Internal Stress and Connection Resistance Correlation Study of Microbump Bonding," IEEE, vol. 24, No. 3, Sep. 2001. pp. 493-499.
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Fig.1A

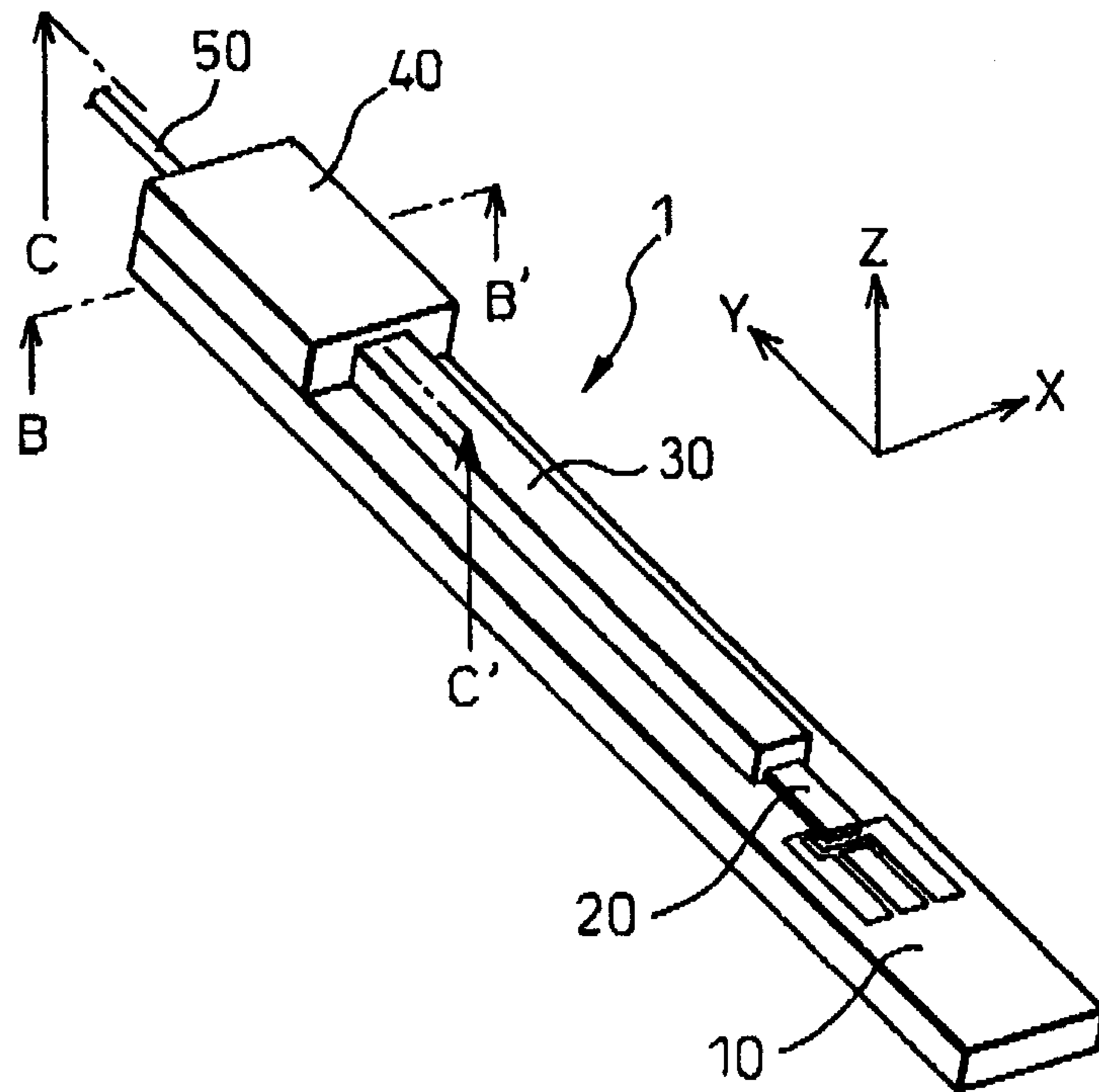


Fig.1B

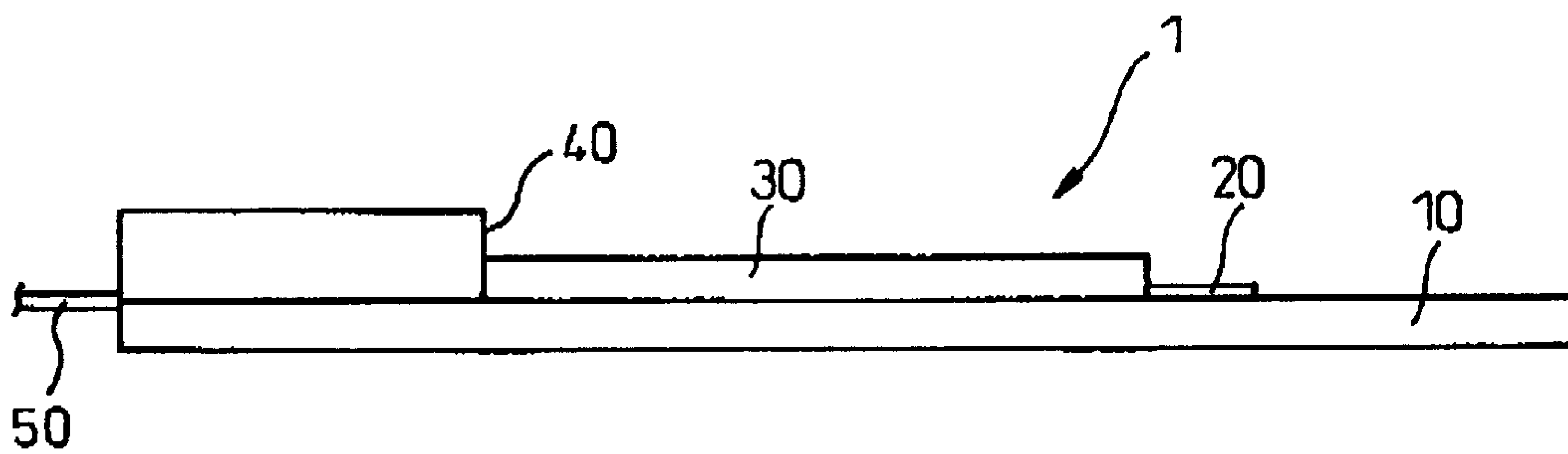


Fig.2

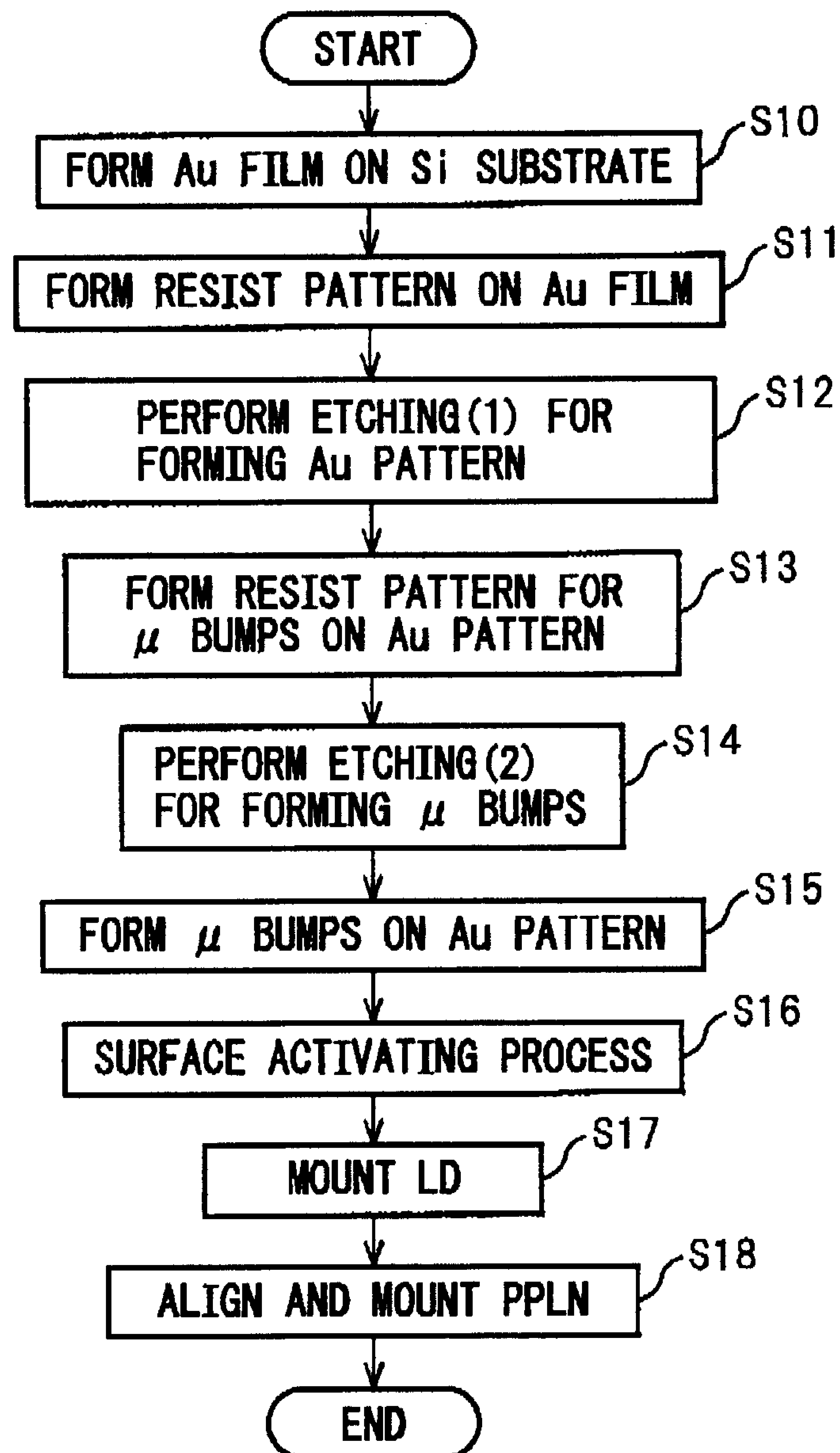


Fig.3A

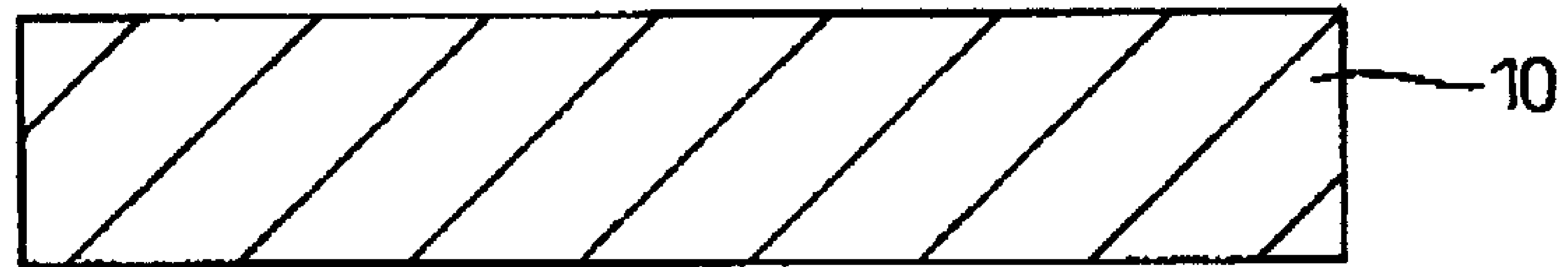


Fig.3B

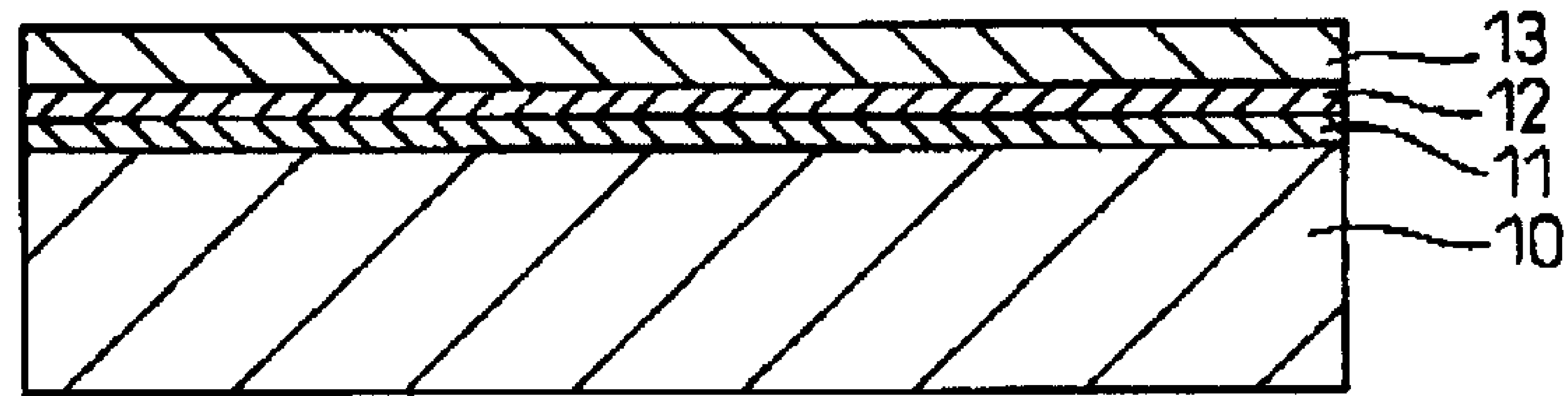


Fig.3C

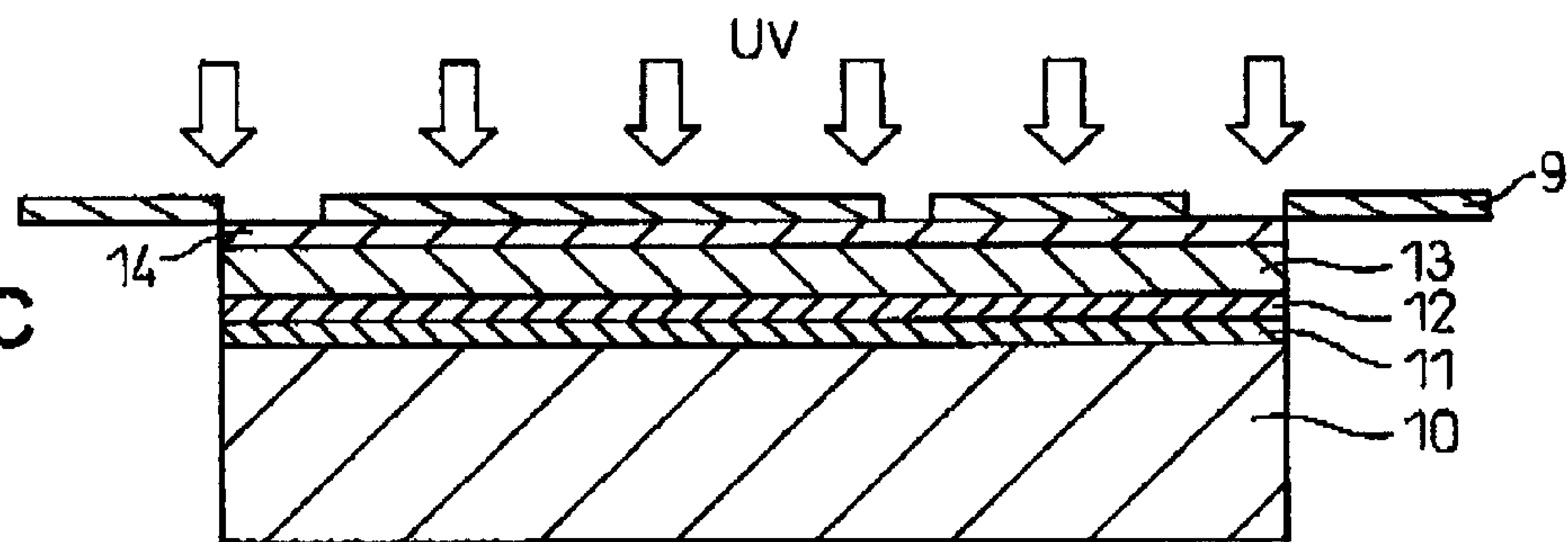


Fig.3D

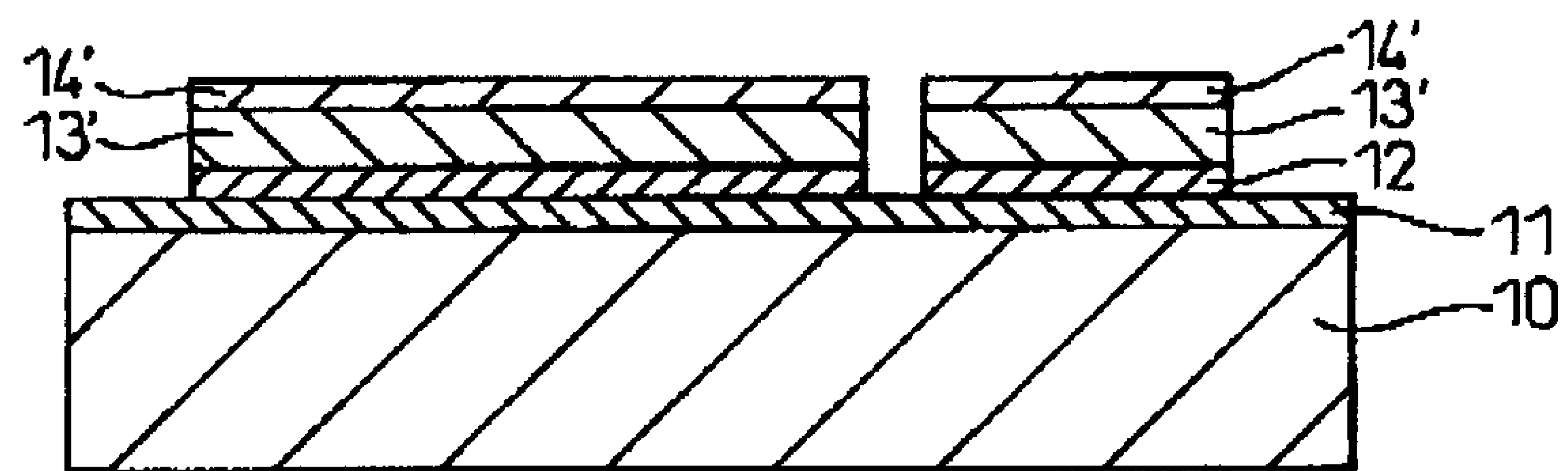


Fig.4A

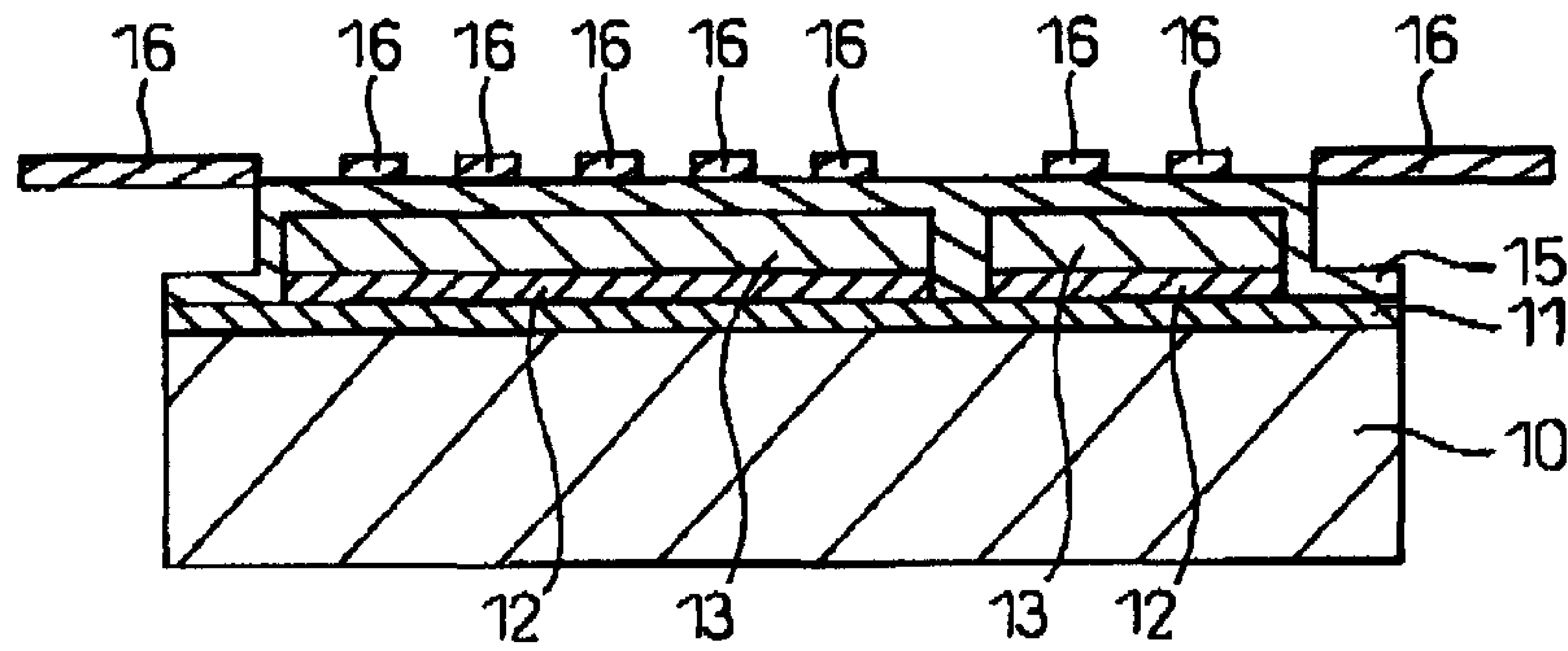


Fig.4B

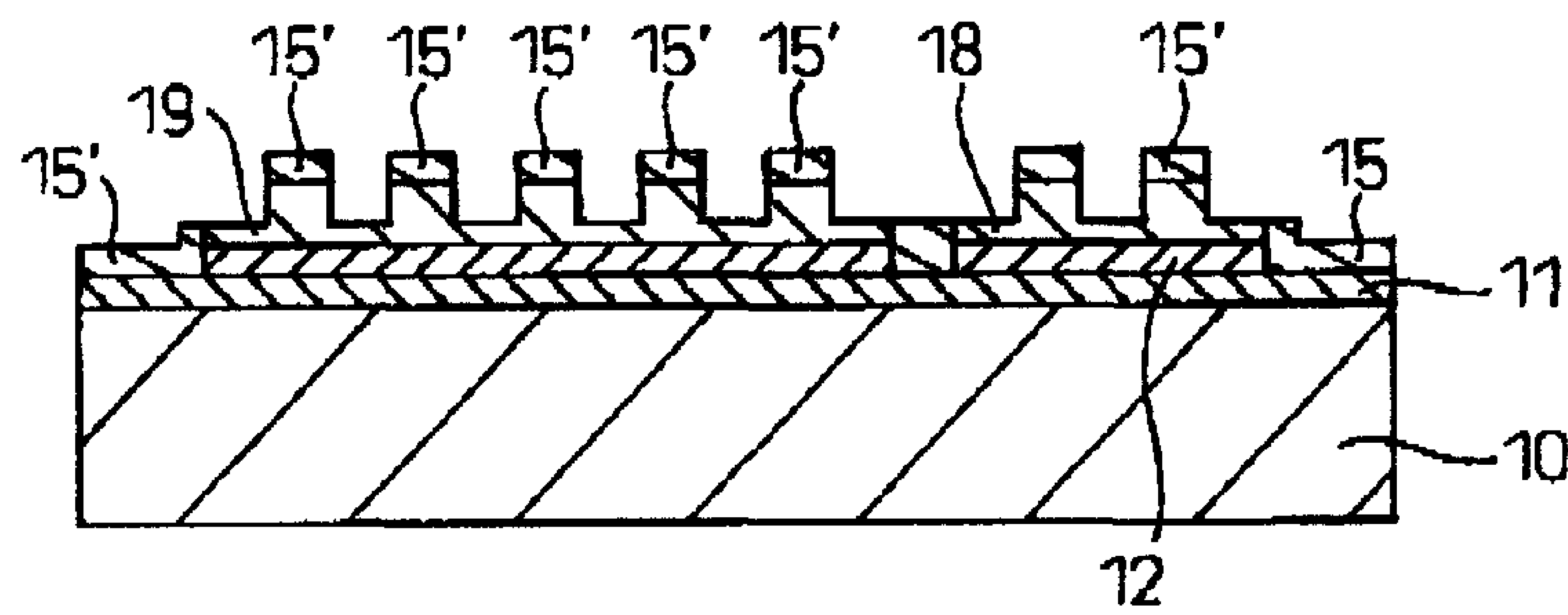


Fig.4C

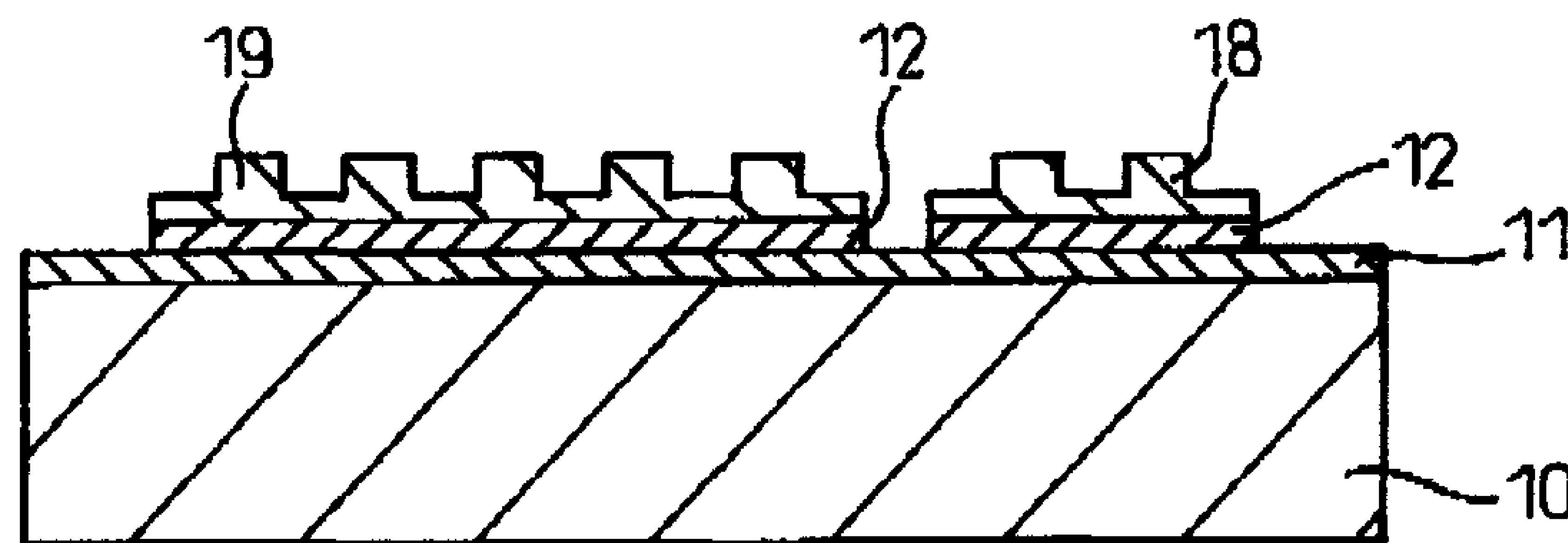


Fig.5A

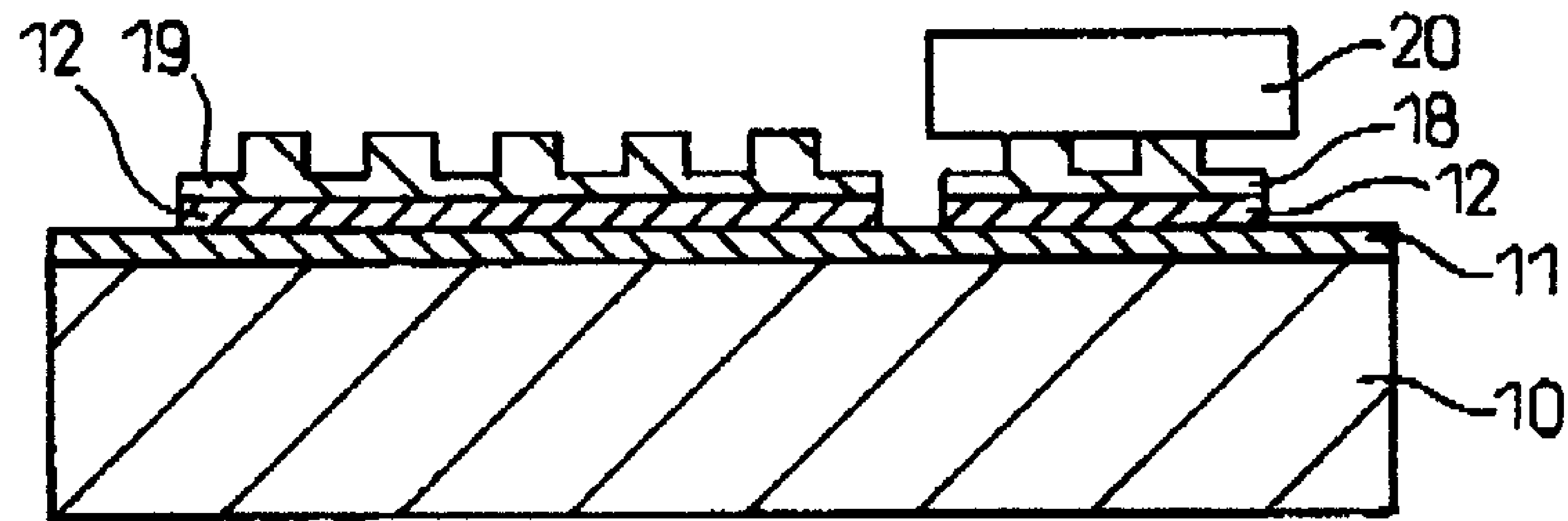


Fig.5B

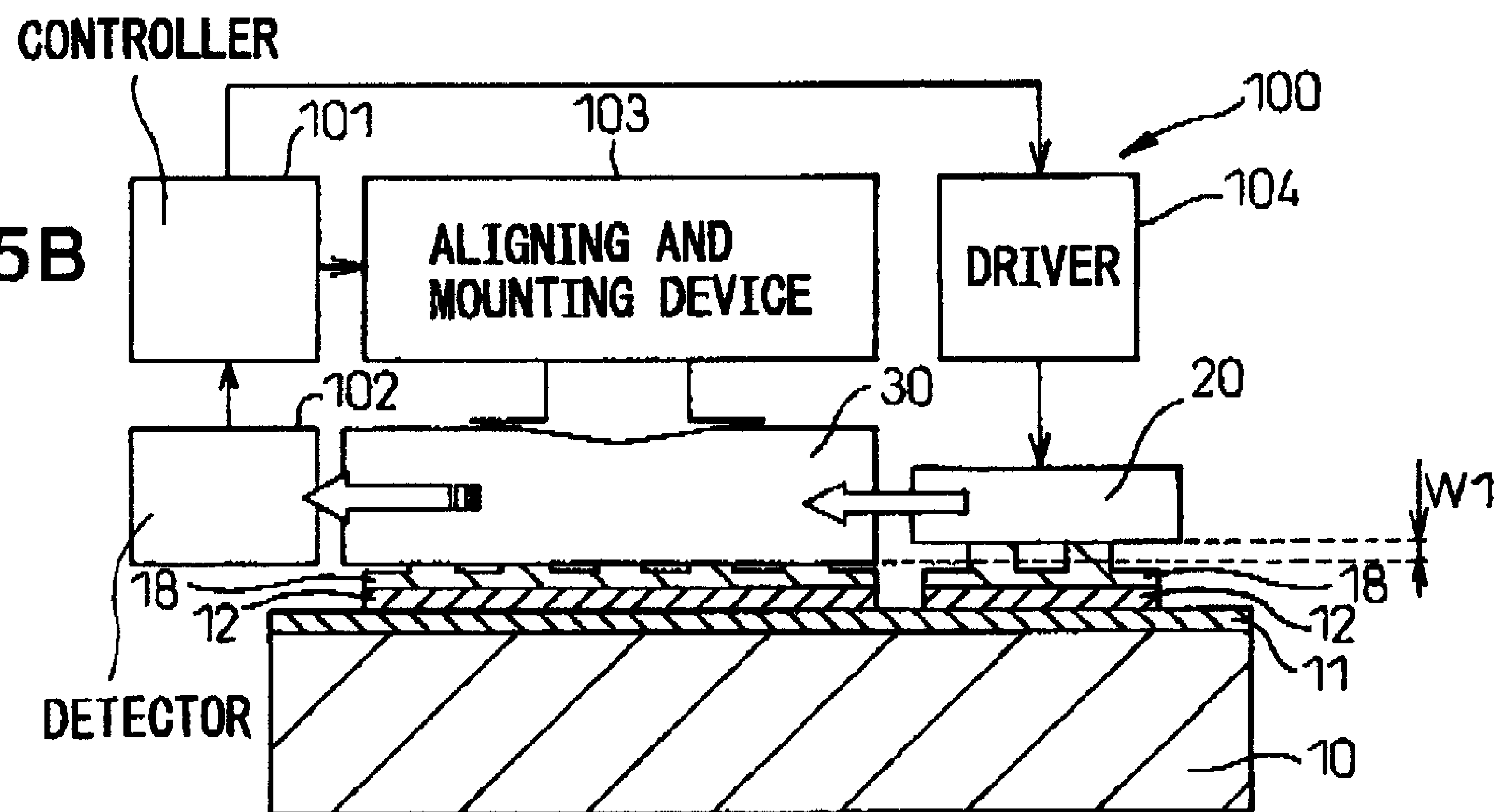


Fig.5C

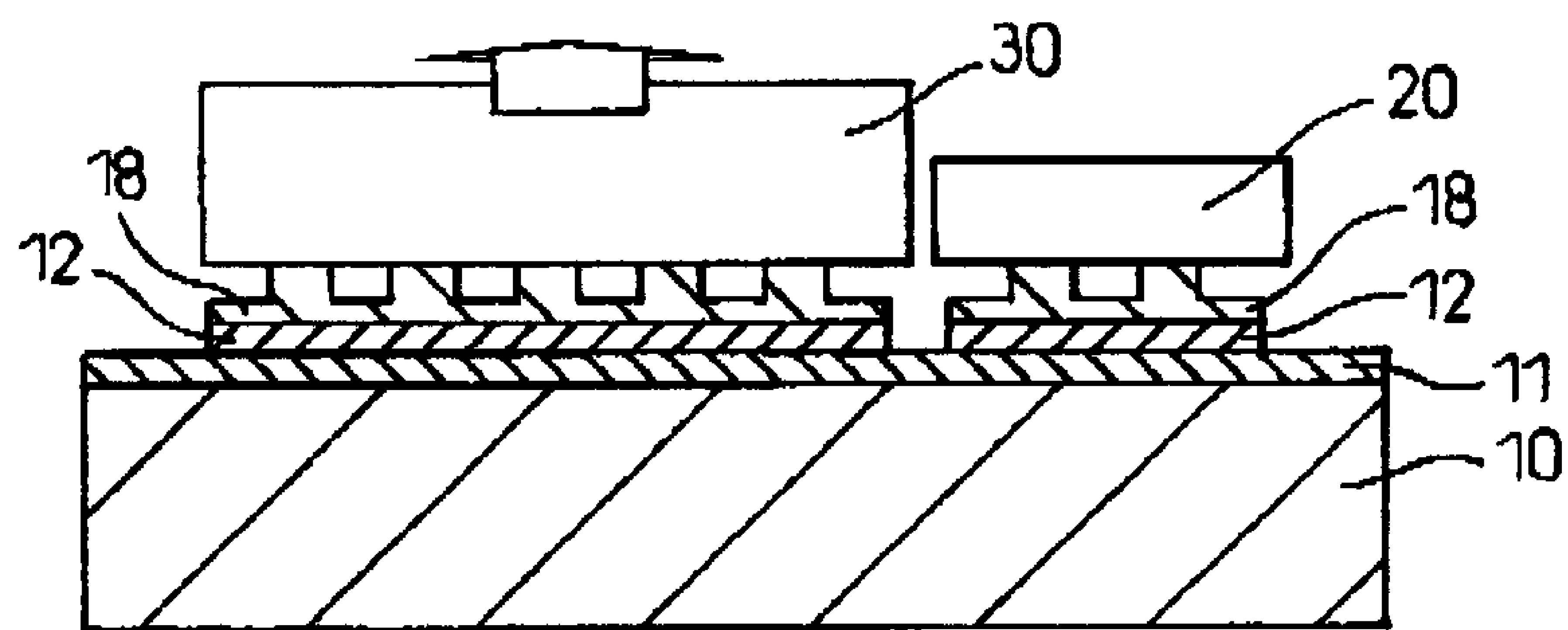
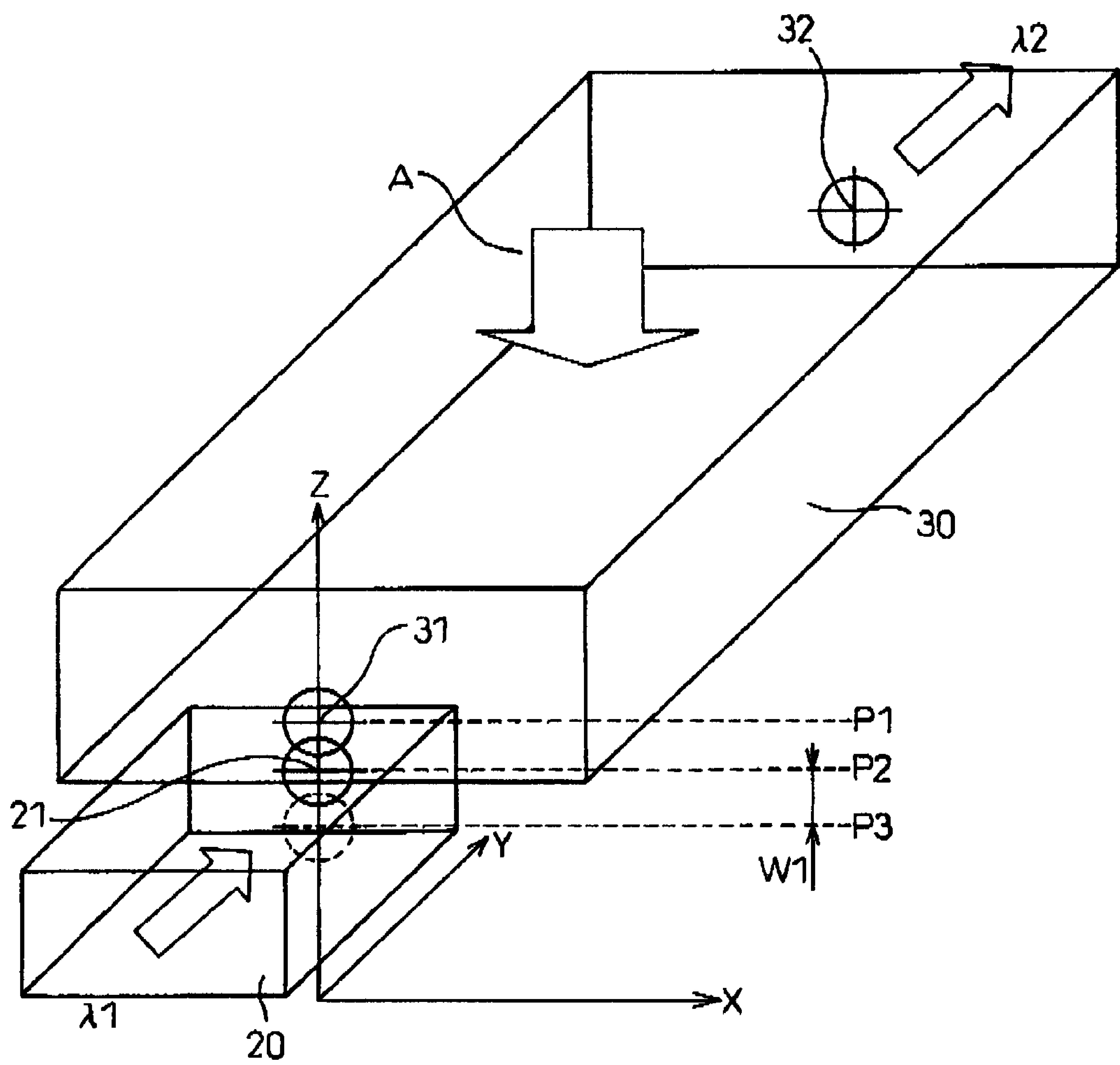


Fig.6



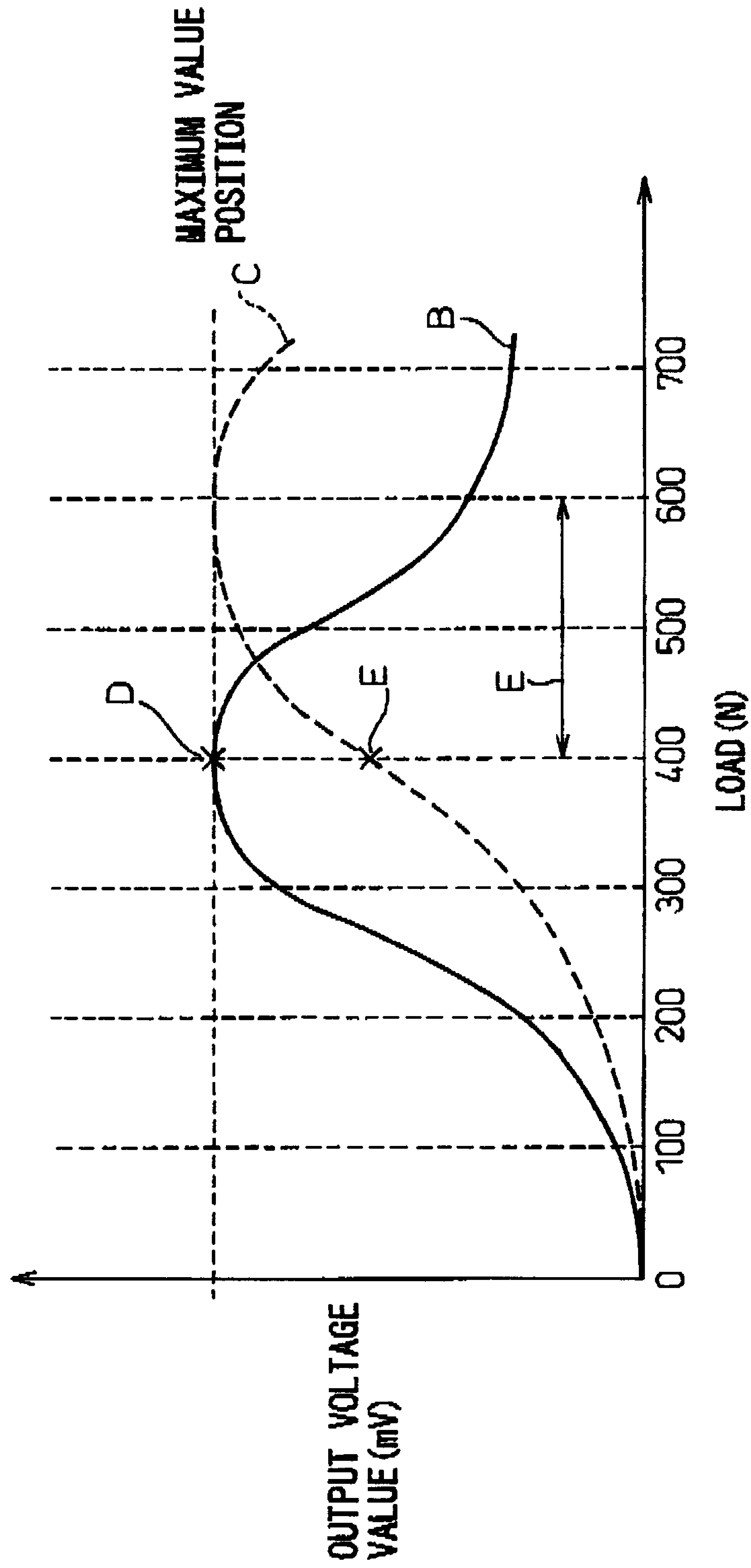


Fig. 7
MAXIMUM VALUE POSITION
C
B
D
E
E
OUTPUT VOLTAGE VALUE (mV)
LOAD (N)
0
100
200
300
400
500
600
700

Fig.8

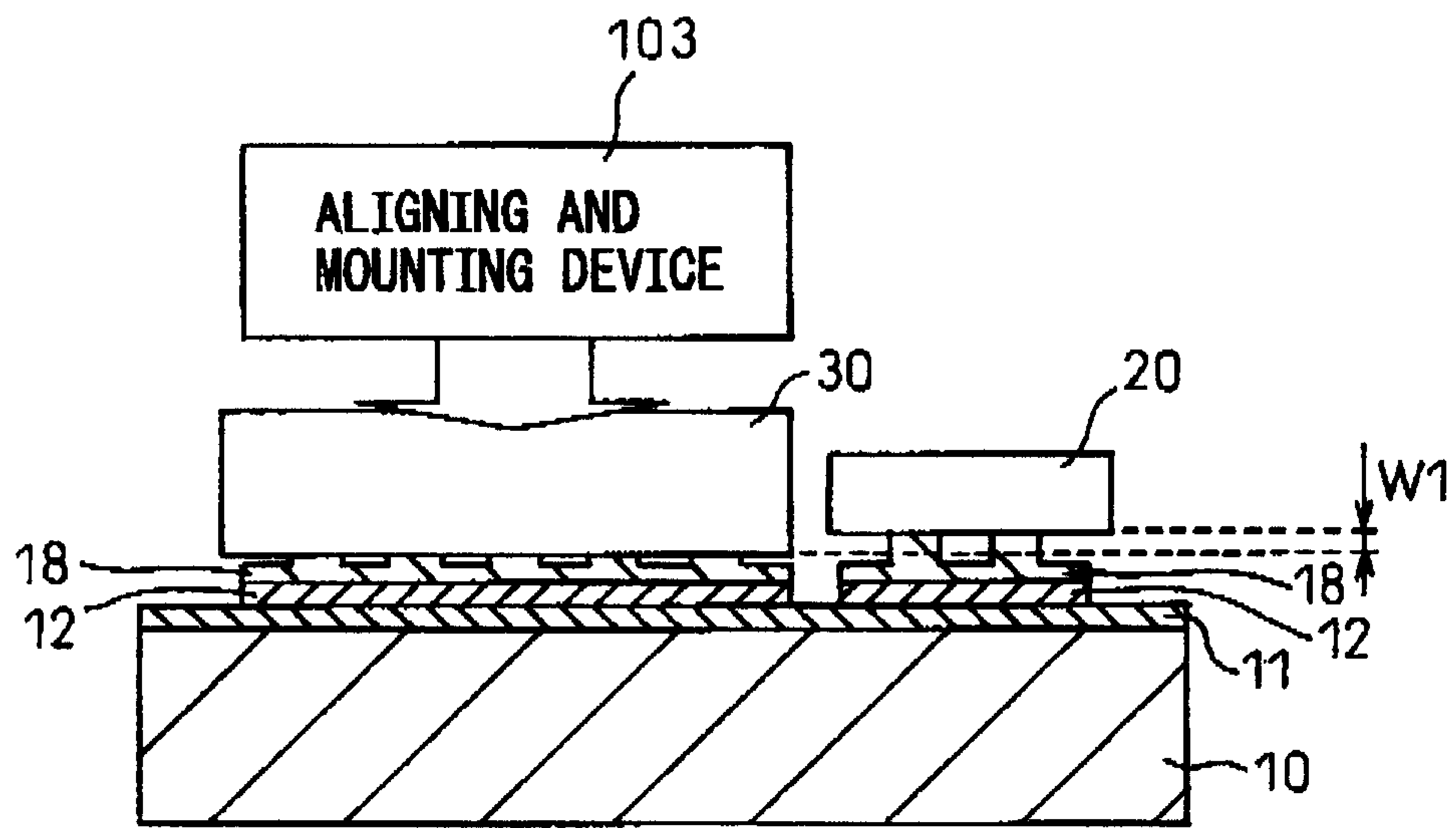


Fig.9A

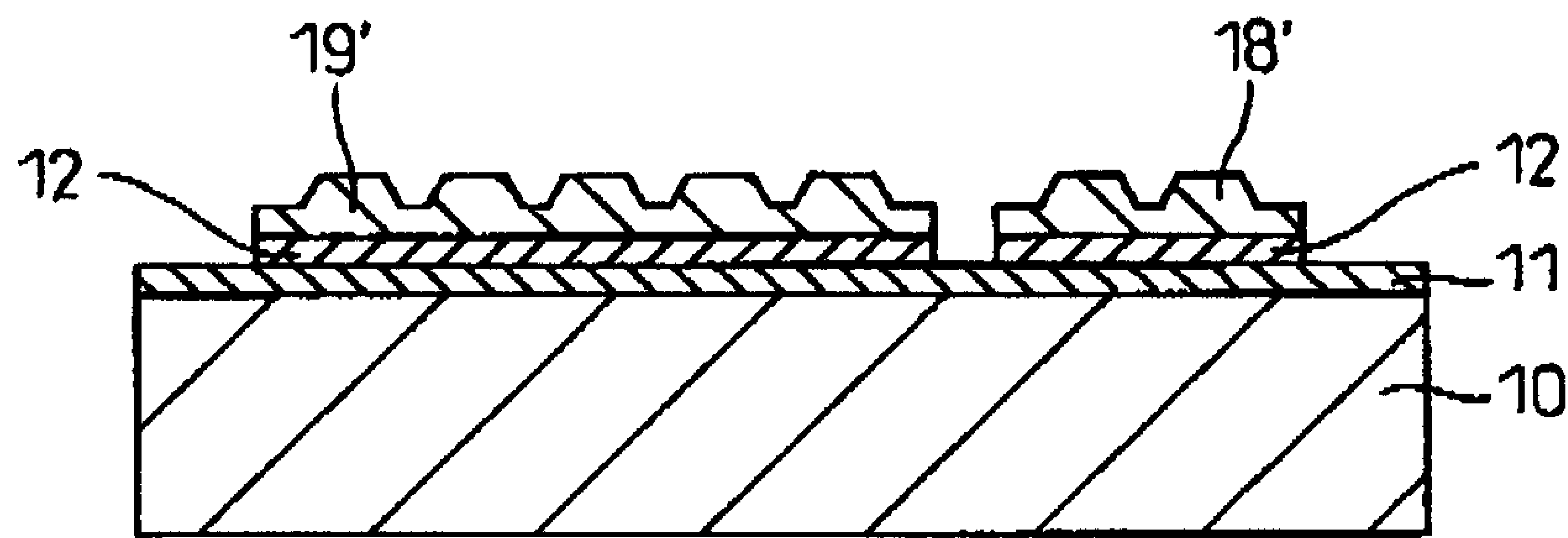


Fig.9B

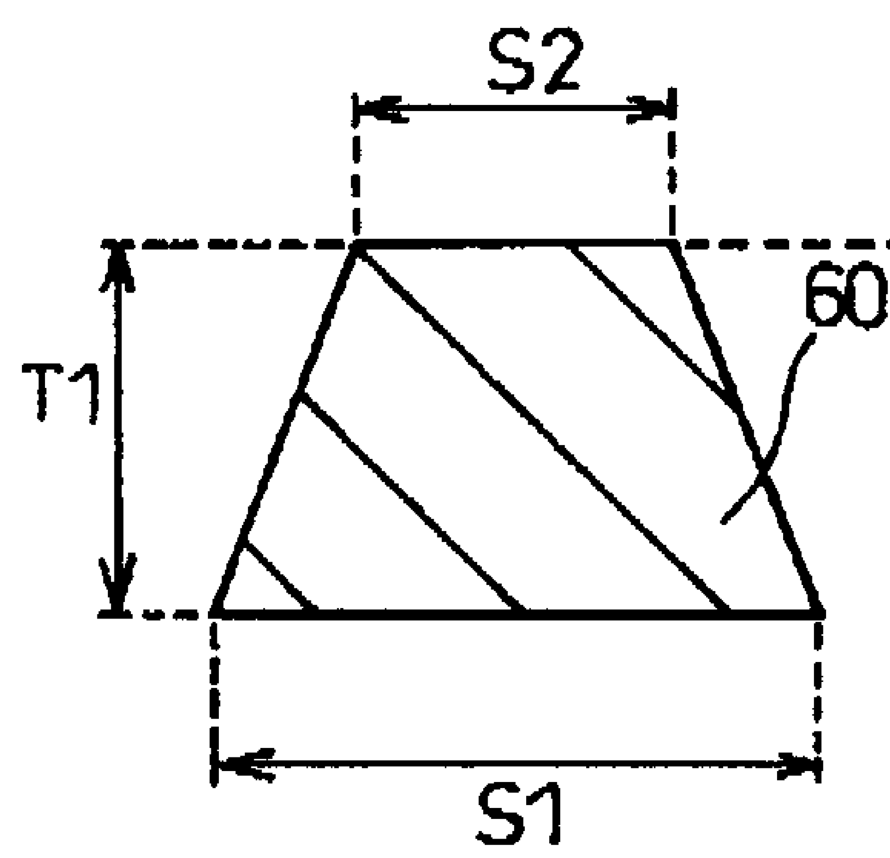


Fig.9C

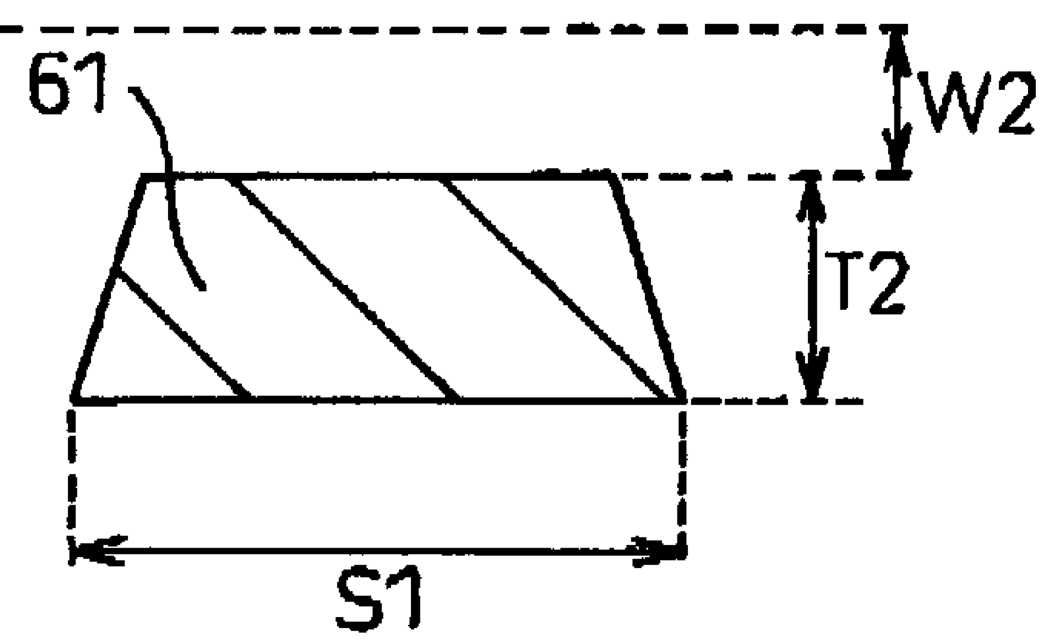


Fig.10

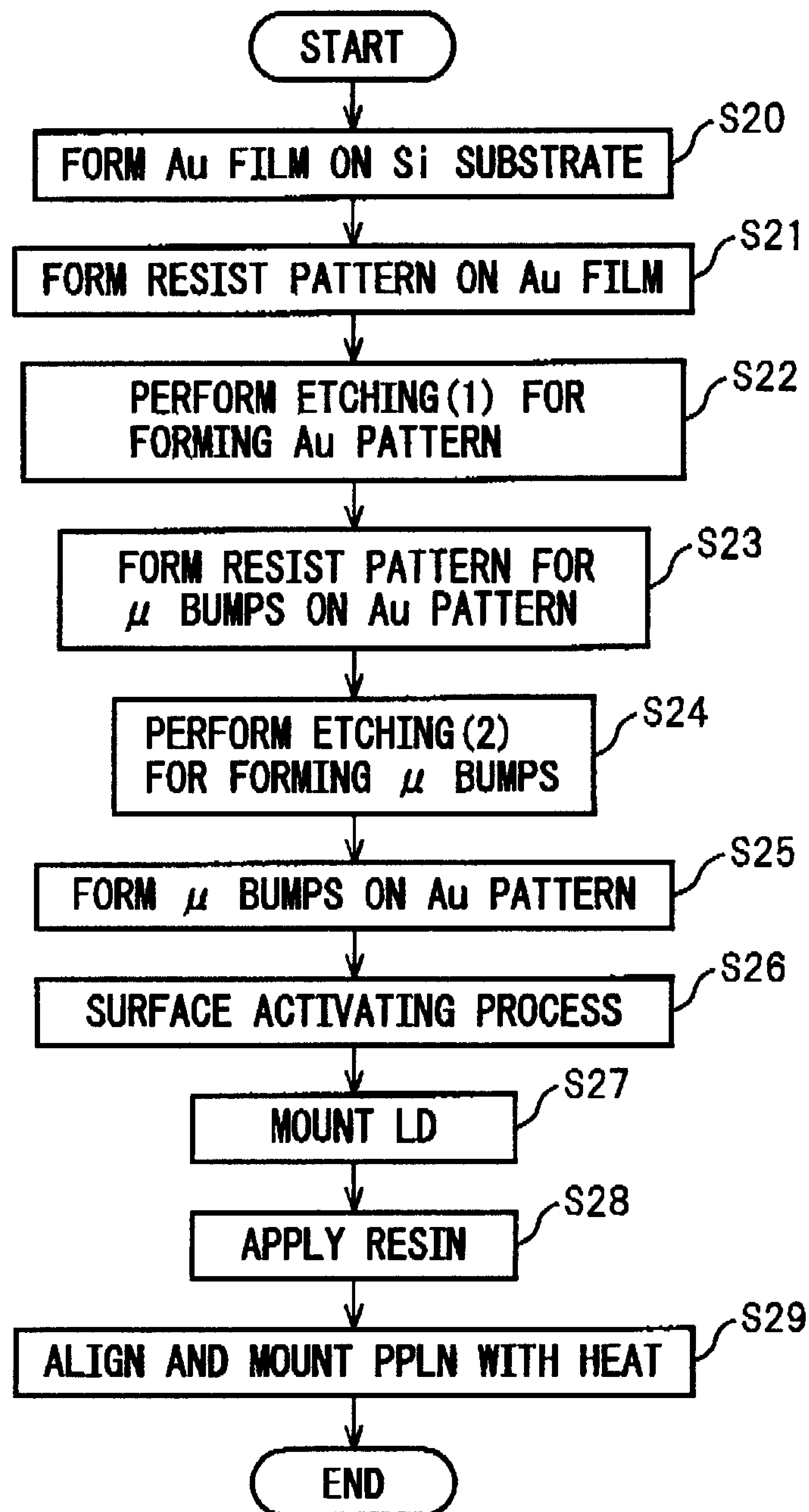


Fig.11A

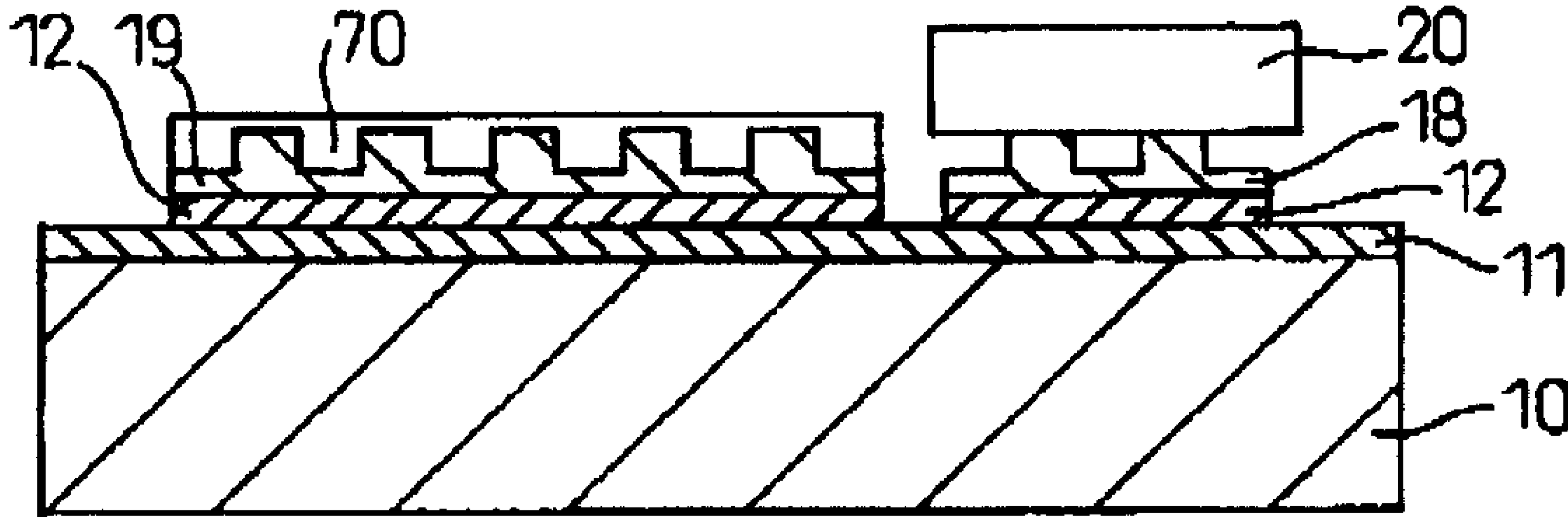


Fig.11B

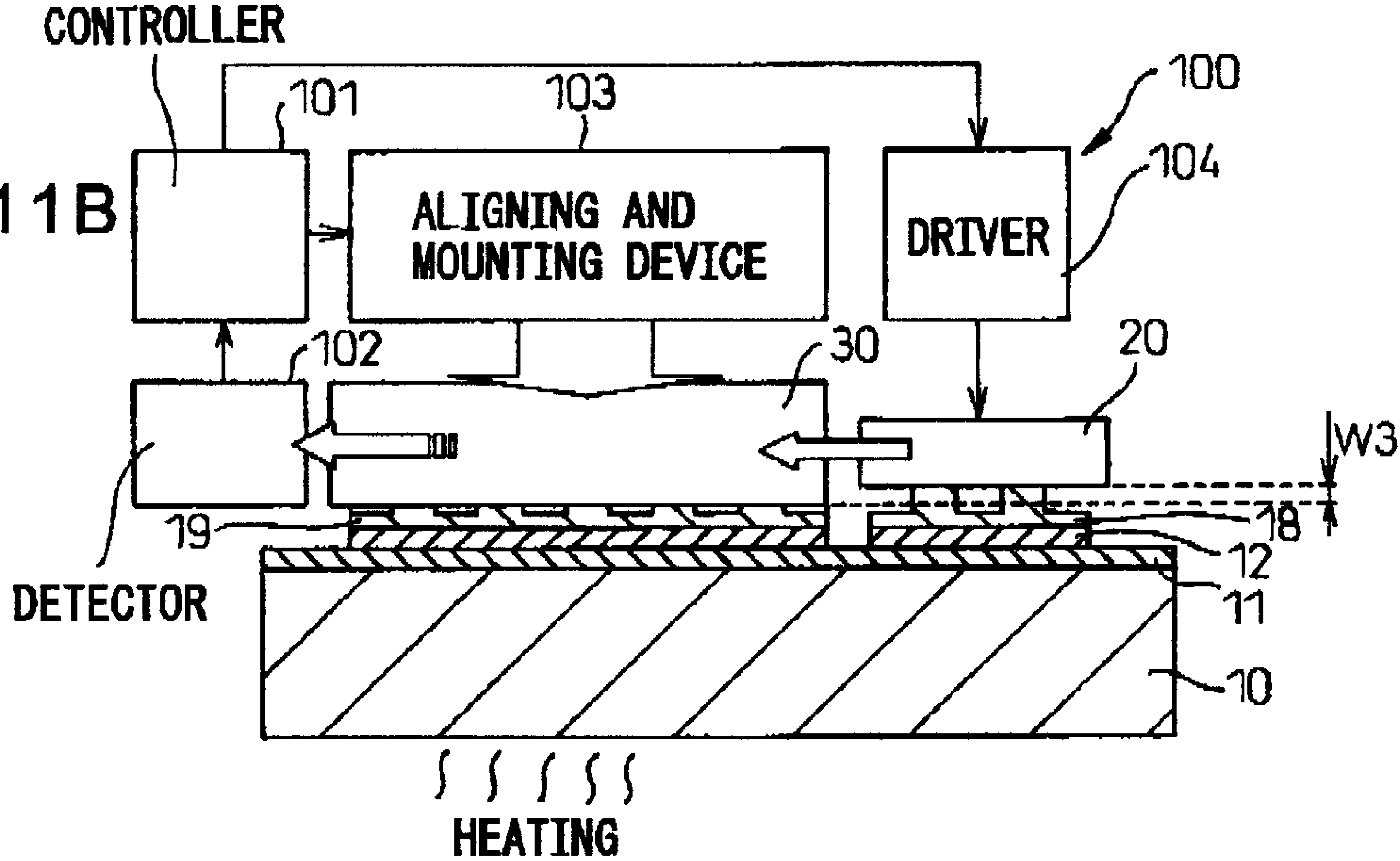


Fig.11C

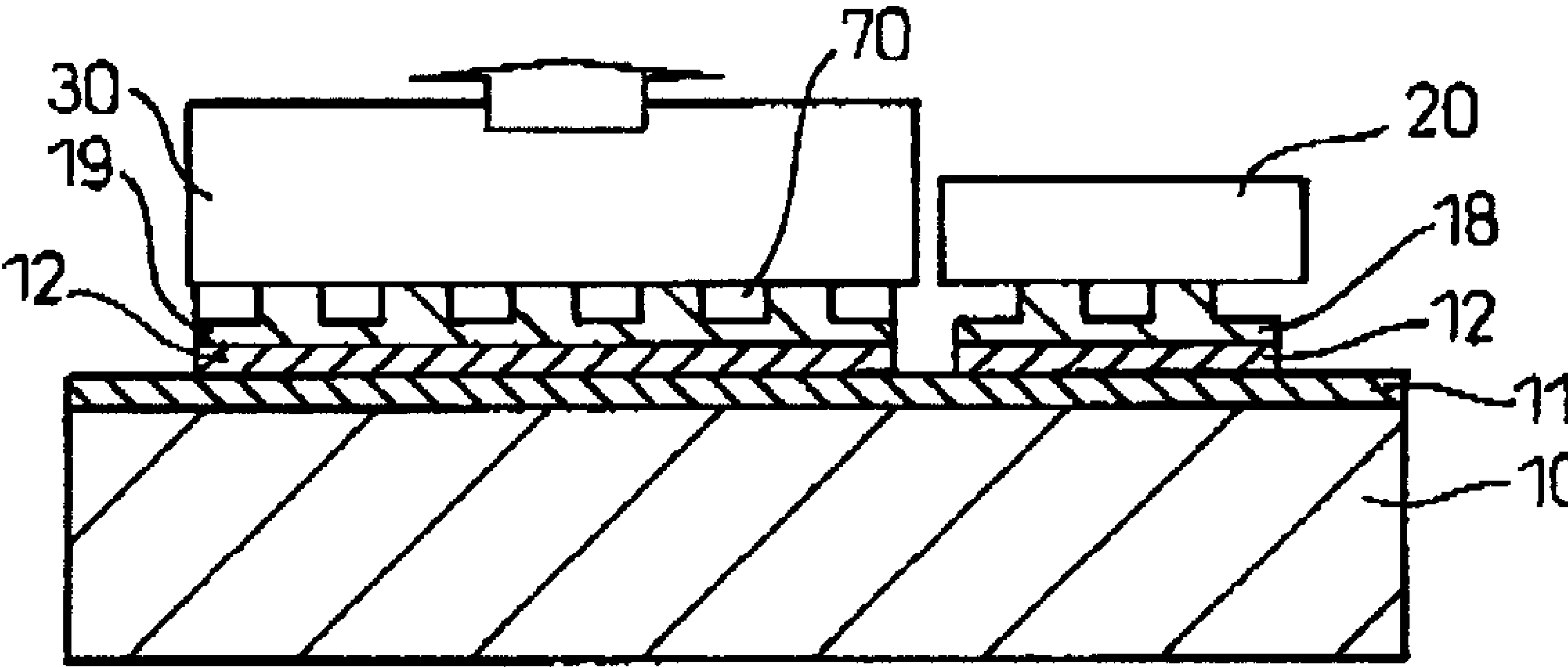


Fig.12

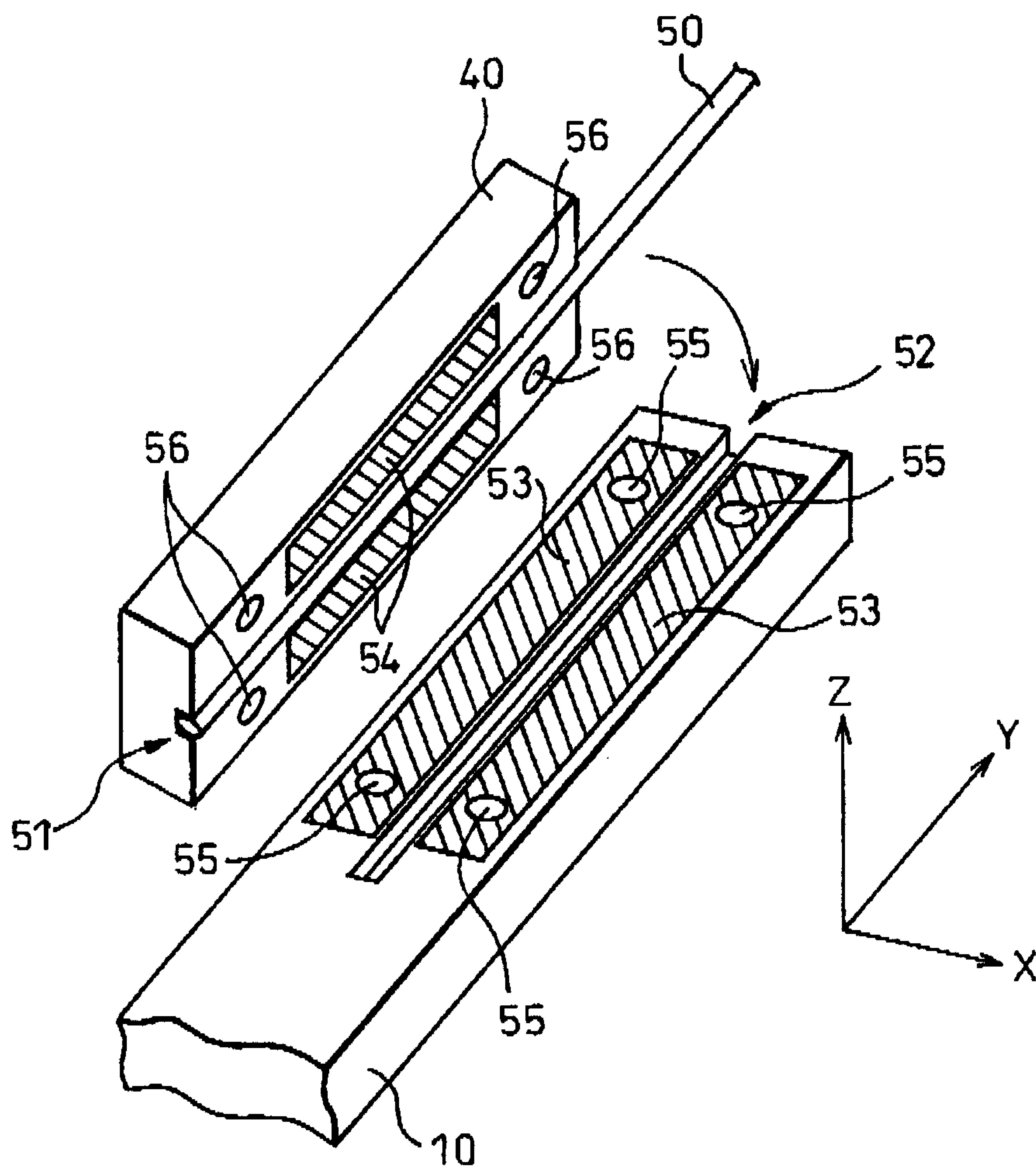


Fig.13A

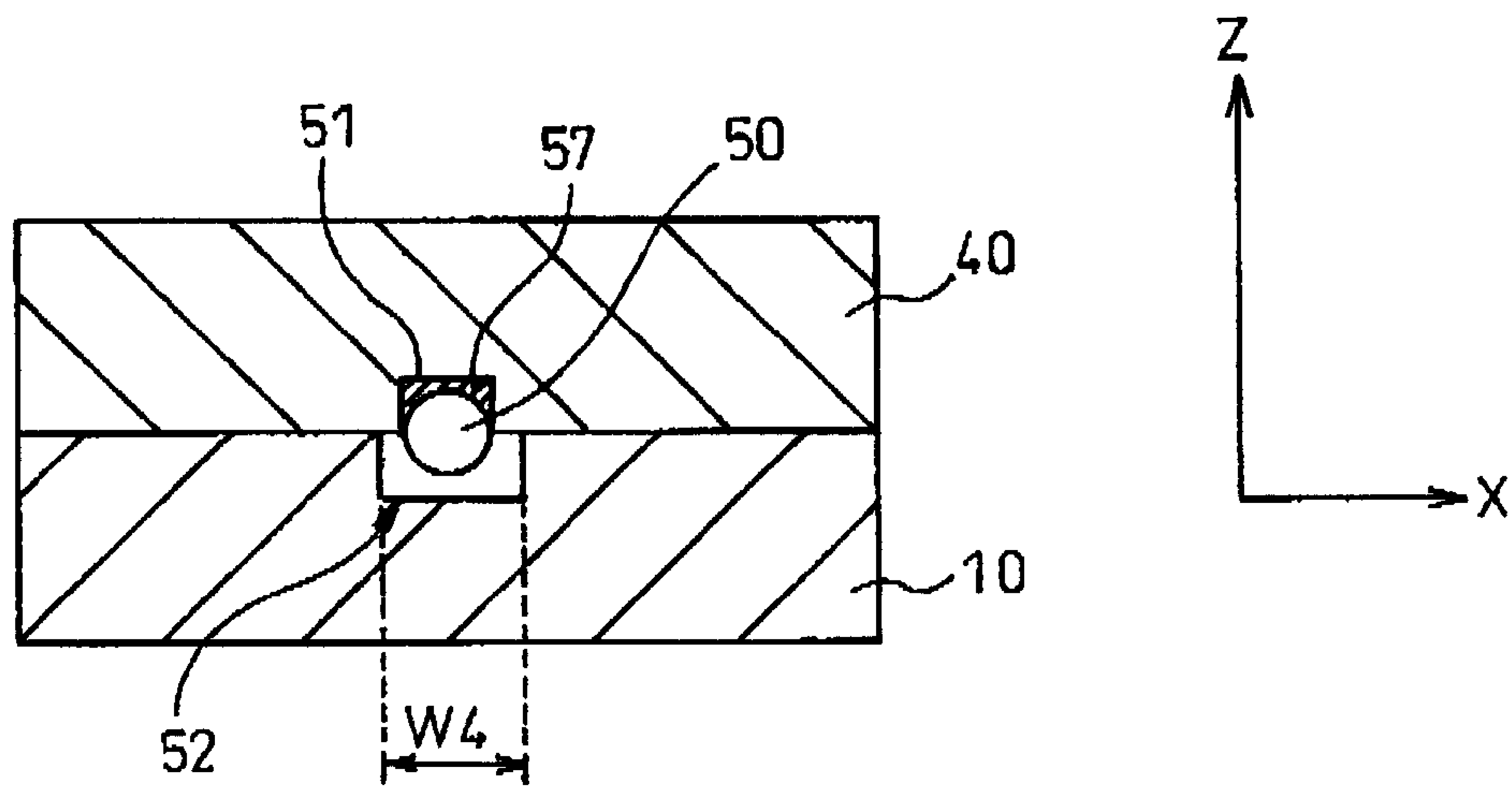
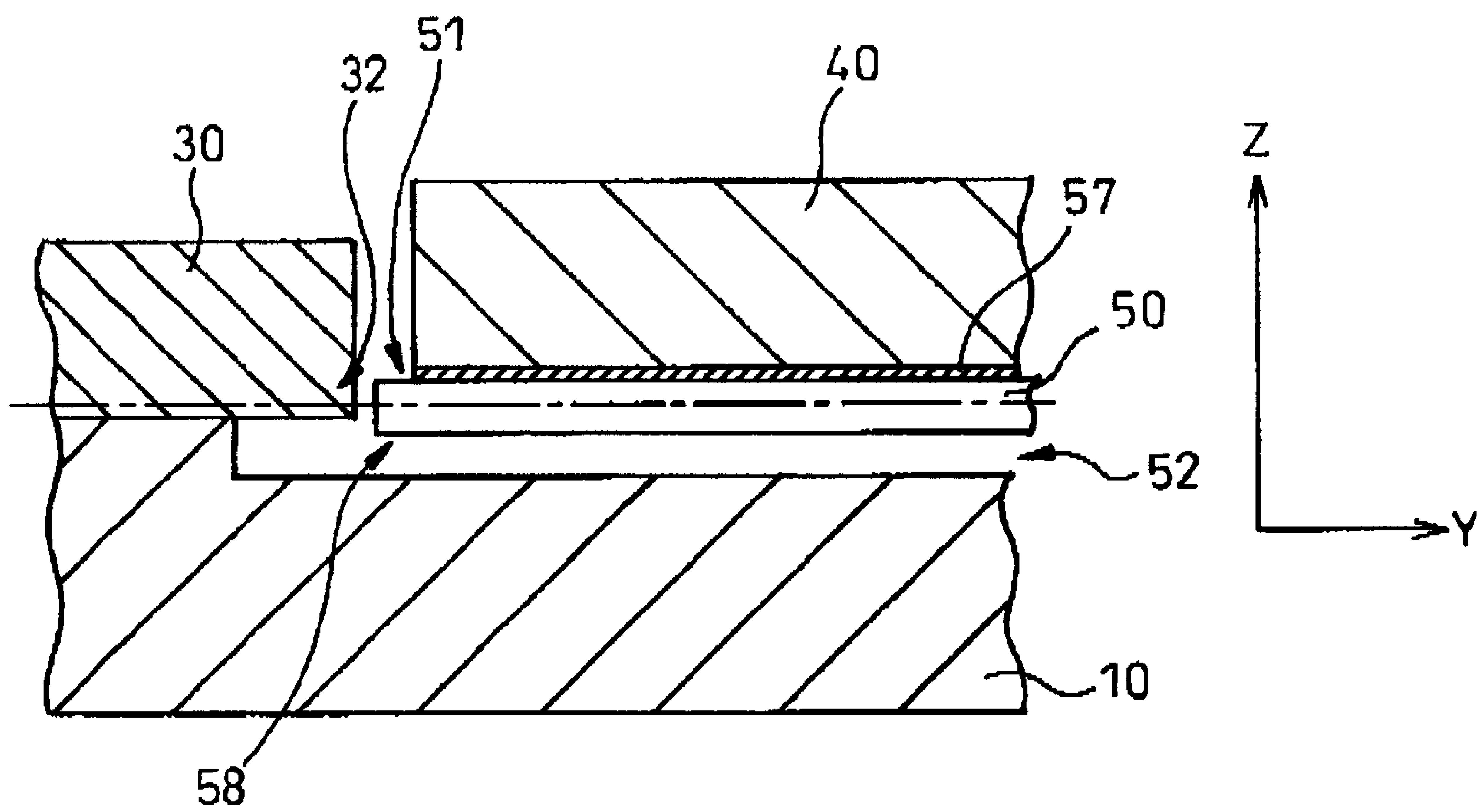


Fig.13B



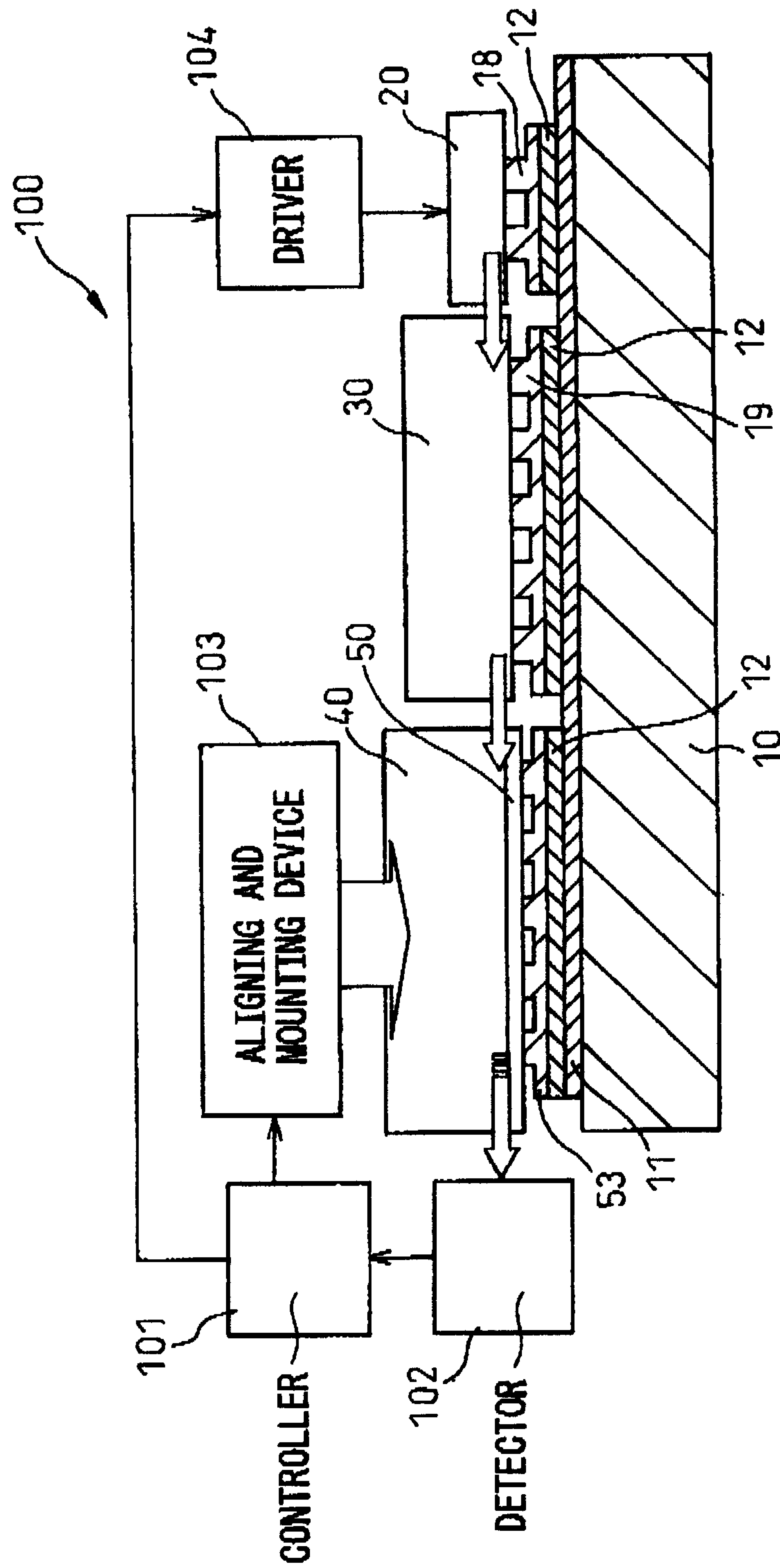


Fig. 14

METHOD OF MANUFACTURING OPTICAL MODULE

The entire content of Japanese Patent Application No. 2011-060916 is hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates to a method of manufacturing an optical module and, more specifically, to a method of manufacturing an optical module including a plurality of optical devices bonded by using bonding bumps.

BACKGROUND OF THE INVENTION

A method of mounting a semiconductor laser element, and joining a photodiode to a copper heat sink using bonding bumps to optically align the semiconductor laser element and the photodiode with high precision is known (for example, refer to Japanese Unexamined Patent Application Publication No. H10-208269 (FIG. 1)).

In the method, in the case of joining the photodiode with the bonding bumps, the relationship between pressure applied to the bonding bumps and height of the bonding bumps deformed according to the applied pressure is examined in advance, and a proper application pressure is selected according to the relationship.

SUMMARY OF THE INVENTION

There is however no technique of positioning in the height direction of an optical device in submicron order by pressing bonding bumps.

When a load is applied to the bonding bumps to deform the bonding bumps and, after that, is released, a force of returning from the deformed position to the original position acts on the deformed bonding bumps by elasticity of the bonding bumps. Even if the optical devices are aligned in a state where the load is applied to the bonding bumps, when the load is released (the applied load is removed), the bonding bumps are deformed again to return to the original state. The relative positions of the optical devices change which is inconvenient.

The re-deformation that the bonding bumps are deformed again to the state before the deformation after the load is released will be called "elastic return of bonding bumps", and the deformation amount will be called "elastic return amount". The "elastic return amount" changes according to the amount of a load applied, the material of the bonding bumps, the shape of the bonding bumps, and the like.

Therefore, an object of the present invention is, to provide a method of manufacturing an optical module to solve the problem.

Another object of the invention is to provide a method of manufacturing an optical module in which optical devices can be optically aligned with high precision regardless of an elastic return of bonding bumps.

A method of manufacturing an optical module according to the present invention includes steps of forming bonding bumps made of metal on a substrate, and bonding a second optical device on the bonding bumps by applying a load so that the bonding bumps are deformed only by a predetermined amount from a position where a first optical device and the second optical device are optically coupled most efficiently and, after that, releasing the load.

According to the present invention, the second optical device is bonded on the bonding bumps based on the elastic return amount of the bonding bumps. Consequently, also in a state in which the load is released, the first and second optical devices can be aligned with high precision.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B are diagrams illustrating a semiconductor laser module **1**.

FIG. **2** is a flowchart for explaining processes of manufacturing the semiconductor laser module **1**.

FIGS. **3**A, **3**B, **3**C and **3**D are diagrams (**1**) illustrating processes of manufacturing the semiconductor laser module **1**.

FIGS. **4**A, **4**B and **4**C are diagrams (**2**) illustrating processes of manufacturing the semiconductor laser module **1**.

FIGS. **5**A, **5**B and **5**C are diagrams (**3**) illustrating processes of manufacturing the semiconductor laser module **1**.

FIG. **6** is a diagram illustrating the positional relation between an LD element **20** and a PPLN element **30**.

FIG. **7** is a graph showing the relation between output voltage of a detector **102** and a load applied by an aligning and mounting device **103**.

FIG. **8** is a diagram showing another example of the process of manufacturing the semiconductor laser module **1**.

FIGS. **9**A, **9**B and **9**C are diagrams for explaining other microbumps.

FIG. **10** is a flowchart for explaining processes of another semiconductor laser module **2**.

FIGS. **11**A, **11**B and **11**C are diagrams illustrating processes of manufacturing the another semiconductor laser module **2**.

FIG. **12** is a diagram for explaining bonding between a substrate **10** and a sub-substrate **40**.

FIGS. **13**A and **13**B are diagrams illustrating the positional relationship between the PPLN element **30** and a fiber **50**.

FIG. **14** is a diagram (**4**) illustrating the process of manufacturing the semiconductor laser module **1**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, with reference to the drawings, a method of manufacturing an optical module according to the present disclosure will be described. It should be noted that the technical scope of the present invention is not limited to embodiments of the invention but covers the invention described in the claims and its equivalent.

FIG. **1**A is a perspective view of a semiconductor laser module **1** as an example of an optical module and FIG. **1**B is a side view in the Y-axis direction of the semiconductor laser module **1**.

The semiconductor laser module **1** includes a silicon substrate **10**, an LD (Laser Diode) element **20**, a PPLN (Periodically Poled Lithium Niobate) element **30** for converting the wavelength of light emitted from the LD element **20**, a sub-substrate **40** made of silicon or glass, and an optical fiber **50**. For example, the semiconductor laser module **1** functions to convert single-mode laser near-infrared light having wavelength of 1,064 nm emitted from the LD element **20** to green laser light having wavelength of **532** nm in the PPLN element **30** and emit the green laser light. The light emitted from the PPLN element **30** is transmitted through the single-mode optical fiber (SMF) **50** bonded to the silicon substrate **10** via the sub-substrate **40**.

In the semiconductor laser module **1**, elements are optically coupled so that light emitted from the LD element **20** can efficiently enter the PPLN element **30**. To increase the optical coupling efficiency, those elements are requested to be

aligned at extremely high precision. The positional precision in the plane direction (XY plane) on the silicon substrate **10** in FIG. **1**A is adjusted by a mounting device at the time of mounting by providing reference marks such as alignment marks on the silicon substrate **10**.

However, normally, with respect to the precision in the height direction (Z direction) in FIG. **1**A, without taking any measure, the mounting height is determined by contact points between the silicon substrate **10** and each of the LD element **20** and the PPLN element **30**. Consequently, by forming microbumps as bonding bumps which will be described later on the silicon substrate **10** and deforming the microbumps by applying a predetermined load to the microbumps at the time of mounting the PPLN element **30**, the precision in the height direction (z direction) is maintained.

In the case of mounting the LD element **20** and the PPLN element **30** on the silicon substrate **10**, a bonding material such as resin, AuSn, or solder can be used. Although the position adjustment can be performed by vertically moving the elements during the bonding material is in a liquid form, when the bonding material is cooled and solidified, the bonding material is shrunk and deformed unpredictably. It is consequently difficult with high-precision to adjust the position in the height direction (Z direction).

The semiconductor laser module **1** is an example of the optical module. It is not interpreted that the optical module is limited to the semiconductor laser module **1**. The optical module can be preferably applied to other modules each having two or more optical devices optically coupled. For example, as will be described later, the optical module can be used for optical coupling between the LD element **20** and the PPLN element **30** or optical coupling between the PPLN element **30** and the optical fiber **50** fixed to the sub-substrate **40**. The optical coupling denotes that the positional relation of optical devices is determined so that light output from one of the optical devices directly enters the other optical device.

With reference to FIG. **2** to FIG. **5**C, a part regarding bonding of the LD element **20** and the PLLN element **30**, in processes of manufacturing the semiconductor laser module **1** as an example of the optical module will be described. FIG. **2** is a flowchart for explaining processes of manufacturing the semiconductor laser module **1**. FIGS. **3**A to **3**D to FIGS. **5**A to **5**C are diagrams for more specifically explaining the processes of manufacturing the semiconductor laser module **1** illustrated in FIG. **2**.

First, the silicon substrate **10** is prepared. FIG. **3**A is a cross sectional view of the silicon substrate **10**.

Next, the entire silicon substrate **10** is heated in an oxidizing atmosphere and an SiO_2 (silicon dioxide) thin film **11** is formed on the silicon substrate **10**. A Ti (titanium) thin film **12** is formed on the SiO_2 thin film **11** by vapor deposition. Further, an Au layer **13** having a thickness of 3 μm is formed on the Ti thin film **12** by vapor deposition (S**10**) (refer to FIG. **3**B). The Au layer **13** may be formed by, in addition to vapor deposition, sputtering, electrodeposition, or the like. The SiO_2 thin film **11** functions as an insulating layer insulating between the silicon substrate **10** and microbumps **18** which will be described later. The Ti thin film **12** is formed to increase adhesion between the SiO_2 thin film **11** and the Au layer **13**.

Subsequently, a photoresist layer **14** is formed on the Au layer **13**, a mask layer **9** is disposed, and ultraviolet light is applied so that a photoresist **14'** corresponding to the mask layer **9** is formed (S**11**) (refer to FIG. **3**C).

The Au layer **13** and the Ti thin film **12** out of the part in which the photoresist **14'** is formed are etched by dry etching to form an Au layer pattern **13'** (S**12**) (refer to FIG. **3**D). The Au layer pattern **13'** may be formed by wet etching in place of dry etching.

After removing the photoresist **14'**, the photoresist layer **15** is formed again, a mask layer **16** is disposed, and ultraviolet light is applied so that a photoresist **15'** corresponding to the mask layer **16** is formed (S**13**) (refer to FIG. **4**A).

The Au layer pattern **13'** out of the part in which the photoresist **15'** is formed is half-etched by dry etching to form the microbumps **18** and microbumps **19** (S**14**) (refer to FIG. **4**B). The microbumps **18** and **19** may be formed by wet etching in place of dry etching. The half-etching is etching performed so that the pattern out of the part in which the photoresist **15'** is formed is not entirely removed but partially remains. In the embodiment, on the outside of the part in which the photoresist **15'** is formed, etching is performed so that the thickness of Au layer pattern **13'** is 1 μm.

Subsequently, the photoresist **15'** is removed, and formation of the microbumps **18** and **19** on the silicon substrate is completed (S**15**) (refer to FIG. **4**C). The microbumps **18** and **19** as a plurality of columnar projections each having a height of 2 μm and a diameter of 5 μm are disposed at pitches of 10 to 25 μm equally in the horizontal direction. The values of shape, height, width, pitch, and the like of the projection are an example and are not limited to the above-mentioned ones. The microbumps **18** and **19** are based on the Au layer **13** formed by sputtering (S**10**) and formed by half-etching (S**14**), so that the heights of all of the projections included in the microbumps **18** and **19** are uniformed with high precision.

By plasma-cleaning an oxide film or an inactive layer such as contamination covering the surface of the microbumps **18** and **19**, the surface is activated (S**16**). Since atoms having high surface energy can be made come into contact with each other by the surface activation, bonding can be firmly performed at room temperature by using adhesion between the atoms. This bonding method does not require special heating and occurrence of a positional deviation of each of the parts caused by residual stress of a thermal expansion coefficient difference is suppressed, so that high-precision alignment and mounting can be performed. The method also has advantages such that destruction of parts caused by the residual stress of a thermal expansion coefficient difference does not easily occur, no stress is applied to the parts, and very little deterioration in functions.

Next, the LD element **20** is mounted on the surface-activated microbumps **18** (S**17**) (refer to FIG. **5**A). An Au layer is formed also on the bonding face of the LD element **20**, and its surface is subjected to activating process. Therefore, only by mounting the LD element **20** on the microbumps **18** and applying a predetermined load, the LD element **20** is surface-activated and bonded to the microbumps **18** and fixed. The LD element **20** can receive supply of drive current via the microbumps **18**. In this case, it is sufficient to perform predetermined patterning for supplying drive current on the Au layer pattern **13'** for forming the microbumps **18**.

The LD element **20** is mounted by a mounting device for attaching not-shown electronic parts on the circuit board. The LD element **20** may be mounted by using an aligning and mounting device **103** used in S**18** to be described later.

The PPLN element **30** is aligned and mounted on the surface-activated microbumps **19** (S**18**) (refer to FIG. **5**B), and the series of processes are finished. An Au layer is formed also on the bonding surface of the PPLN element **30**, and the surface is subjected to the activating process. Therefore, only by mounting the PPLN element **30** on the microbumps **19** and applying a predetermined load, the PPLN element **30** is surface-activated and bonded on the microbumps **19** and fixed.

The alignment and mounting in **S18** is performed by using an aligning and mounting apparatus **100**. The aligning and mounting apparatus **100** includes: a controller **101** constructed by, for example, a PC including a CPU, a predetermined memory, and the like; a detector **102** detecting intensity of a wavelength-converted laser beam output from the PPLN element **30** and outputting detection output voltage v (mV) according to the intensity; the aligning and mounting device **103** capable of mounting an electronic part in a predetermined position on the silicon substrate **20** and applying a load (N) according to a control amount at the time of mounting; and a driver **104** driving the LD element **20** to emit a laser beam.

The controller **101** controls the driver **104** to drive the LD element **20** and make the laser beam enter the PPLN element **30**, and the intensity of the wavelength-converted laser beam emitted from the PPLN element **30** is detected by the detector **102**. Further, the controller **101** controls the aligning and mounting device **103** while monitoring output voltage V detected by the detector **102** to control the load applied to the PPLN element **30**.

FIG. **6** is a diagram illustrating the positional relation between the LD element **20** and the PPLN element **30**.

A laser beam having a wavelength **λ1** emitted from a light emission center **21** of the LD element **20** enters an incident position **31** in the PPLN element **30** and goes out as a laser beam having a wavelength **λ2** from an outgoing center **32** of the PPLN element **30**. As shown in FIG. **6**, the LD element **20** and the PPLN element **30** are mounted on the silicon substrate **10** by the aligning and mounting device **103**, the positional relation in the plane (the positional relation in the X-Y axis direction) between the light emission center **21** of the LD element **20** and the incident position **31** in the PPLN element **30** is determined with high precision. However, the positional relation in the height direction (Z-axis direction) of the silicon substrate **10** has to be determined with high precision. In FIG. **6**, the arrow A shows a direction in which a load is applied to the PPLN element **30** by the aligning and mounting device **103**.

FIG. **7** is a graph showing the relation between output voltage of the detector **102** and a load applied by the aligning and mounting device **103**.

In FIG. **7**, the curve B indicates the relation between output voltage (mV) of the detector **102** and the load (N) applied by the aligning and mounting device **103** in a state where the load is applied. The curve C indicates the relationship between the output voltage (mV) of the detector **102** and the final load (N) applied by the aligning and mounting device **103** after the load is released. In the example of FIG. **7**, in the state where the load is applied, in the case where the load is **400** (N), the output voltage (mV) of the detector **102** becomes the maximum value (refer to point D). However, after the load is released, in the case where the final load is **400** (N), the output voltage (mV) of the detector **102** does not become the maximum value (refer to point E).

The point D corresponds to the case where the microbumps **19** are deformed by applying a load to the PPLN element **30** to set the incident position **31** of the PPLN element **30** to a position (refer to the position P**2** in FIG. **6**) in which the incident position **31** is most-efficiently optically coupled to the light emission center **21** of the LD element **20** and, in this state, the load is released. The microbumps **19** have a characteristic such that when the load is applied, the microbumps **19** are deformed (pressed) and shrunk. When the load is released by elastic rebound, the force of returning to the original state works, and the microbumps **19** return to the original state only by the elastic return amount. That is, the point E corresponds to the case where when the load is released in the state of the point D, the incident position **31** of the PPLN element **30** moves to another position (for example, refer to the position P**1** in FIG. **6**) by the elastic return.

In the state where the load is released (state where the semiconductor laser module **1** is actually used), the incident position **31** of the PPLN element **30** has to be set to the position (refer to the position P**2** in FIG. **6**) in which the incident position **31** is most-efficiently and optically coupled to the light emission center **21** of the LD element **20**. Consequently, in the aligning and mounting in **S18**, the controller **101** controls the aligning and mounting device **103** as follows. The PPLN element **30** is disposed in the predetermined position of the microbumps **19**. While increasing the load applied, after the output voltage V from the detector **102** becomes the maximum value, a predetermined load amount is applied to further deform the microbumps **19** and, then, the load is released.

Specifically, after the output voltage V from the detector **102** becomes the maximum value (refer to the point D), the controller **101** further applies a predetermined load amount (F: 200(N)) and, after that, the load is released. The predetermined load F is further applied so that the incident position **31** of the PPLN element **30** is pushed into a position (refer to the position P**3** in FIG. **6**) deeply pushed from the light emission center **21** of the LD element **20** only by the distance W**1** shown in FIG. **6**. After that, by releasing the load, the incident position **31** of the PPLN element **30** returns to the position where it is most-efficiently optically coupled to the light emission center **21** of the LD element **20** (refer to P**2** in FIG. **6**) by elastic return (refer to FIG. **5**C).

The above-described predetermined load amount (F: 200 (N)) varies depending on the shape of the aligning and mounting device **103** and the PPLN element **30** to which the load is applied, the material and the shape of the microbumps **19**, and the like. It can be calculated by conducting an experiment to obtain the curves B and C shown in FIG. **7**. In the aligning and mounting in **S18**, after the output voltage V from the detector **102** becomes the maximum value, the controller **101** controls the aligning and mounting device **103** so as to apply a predetermined load. However, the user may control the aligning and mounting device **103** while observing the output voltage V from the detector **102** by a monitor.

FIG. **8** is a diagram showing another example of the process of manufacturing the semiconductor laser module **1**.

With reference to FIG. **8**, the aligning and mounting of the another PPLN element **30** will be described. In the example of FIG. **5**B (**S18** in FIG. **2**), after the output voltage V from the detector **102** becomes the maximum value, the controller **101** controls the aligning and mounting device **103** so as to apply a predetermined load. However, for the microbumps **18** and **19**, the LD element **20**, and the PPLN element **30** manufactured with a predetermined reference, it is not always necessary to make the LD element **20** emit light and individually perform the aligning and mounting according to the output voltage V from the detector **102**.

In the example of FIG. **8**, the load at which the output voltage V from the detector **102** becomes the maximum value (refer to the point D in FIG. **7**) is predicted and, in addition to the load (for example, 400(N)), the above-described predetermined load amount (F: 200(N)) is applied (for example, 600 (N) in total). By the application, the incident position **31** of the PPLN element **30** is pushed into the position (refer to the position P**3** in FIG. **6**) which is further deeply pushed from the light emission center **21** of the LD element **20** only by the distance W**1** shown in FIG. **6** and, after that, the load is released. The incident position **31** of the PPLN element **30**

returns to the position where it is most-efficiently optically coupled to the light emission center **21** of the LD element **20** (refer to P**2** in FIG. **6**) by elastic return. That is, in the example of FIG. **8**, using only the aligning and mounting device **103**, without using the controller **101**, the detector **102**, and the driver **104** shown in FIG. **5**B, the positional relation in the height direction (Z-axis direction) between the PPLN element **30** and the LD element **20** is set.

The method shown in FIG. **8** is different from the manufacturing process of the semiconductor laser module **1** illustrated in FIG. **2** only with respect to the point that only the aligning and mounting device **103** is used and the controller **101**, the detector **102**, and the driver **104** are not used in the aligning and mounting process (S**18** in FIG. **2**). Since the other points, particularly, the process of manufacturing the microbumps **18** and **19** and the method of bonding the LD element **20** and the PPLN element **30** and the microbumps **18** and **19** are the same, their description will not be repeated.

FIGS. **9**A to **9**C are diagrams for explaining other microbumps.

The microbumps **18** and **19** shown in FIGS. **4** and **5** include a plurality of projections each having a columnar shape and having a height of 2 μm and a diameter of 5 μm, which are disposed at pitches of 10 to 25 μm equally in the horizontal direction. Other microbumps **18'** and **19'** shown in FIG. **9**A include a plurality of projections each having a truncated cone shape. FIG. **9**A is a cross section of the microbumps **18'** and **19'** and others, and corresponds to FIG. **4**C. FIG. **9**B is a cross section of a projection part **60** included in the microbumps **18'** and **19'**, and FIG. **9**C is a diagram showing an example of a pressed projection part **61** included in the microbumps **18'** and **19'**.

As shown in FIG. **9**B, in the truncated-cone-shaped projection part **60**, the bottom face has a circular shape having a diameter S**1** (for example, 2 μm), the top face has a circular shape having a diameter S**2** (for example, 1 μm), and height is T**1** (for example, 2 μm). The microbumps **18'** and **19'** include the projection parts **60** which are disposed at pitches of 2 μm and equally in the horizontal direction.

FIG. **9**C shows an example of the projection part **61** which is pressed at the time of aligning and mounting the PPLN element **30**. In the truncated-cone-shaped projection part **61**, the bottom face has a circular shape having a diameter S**1** (for example, 2 μm), and height is T**2** (for example, 1 μm). In this case, therefore, the truncated-cone-shaped projection part is pressed only by distance W**2** (for example, 1 μm) by the aligning and mounting.

The microbumps **18'** and **19'** each having the truncated cone shape of which top face is slightly smaller are pressed more easily as compared with the microbumps **18** and **19** each having a columnar shape shown in FIGS. **4**B and **4**C and FIGS. **5**A to **5**C in the case of applying the same load. There is consequently an effect that the control for alignment is easier (for the reason that the aligning and mounting device **103** does not have to apply a high load).

With reference to FIG. **10** and FIGS. **11**A to **11**C, another method of a part related to bonding of the LD element **20** and the PLLN element **30** in the processes of manufacturing the semiconductor laser module **1** as an example of the optical module will be described. FIG. **10** is a flowchart for explaining processes of the semiconductor laser module **2**. FIGS. **11**A to **11**C are diagrams for explaining processes of manufacturing the semiconductor laser module **2** shown in FIG. **10** more specifically.

The difference between the semiconductor laser module **2** and the foregoing semiconductor laser module **1** is the point that, in the semiconductor laser module **2**, the PPLN element **30** and the microbumps **19** are fixed by a thermosetting bonding resin. Therefore, the Au layer is not formed on the substrate on the microbumps side of the PPLN element **30**. Since it is unnecessary to supply current to the PPLN element **30** in the semiconductor laser module **2**, the MN element **30** is fixed on the microbumps **19** by a thermosetting bonding resin without using a high-cost Au layer. Except for this point, the semiconductor laser module **2** is similar to the semiconductor laser module **1**. Accordingly, S**20** to S**25** and S**27** in the processes of manufacturing the semiconductor laser module **2** shown in EXG. **10** are the same as S**10** to S**15** and S**17** in the processes of manufacturing the semiconductor laser module **1** shown in FIG. **2**, and their description will not be repeated.

In the processes of manufacturing the semiconductor laser module **2** shown in FIG. **10**, the surface activation is performed by performing cleaning and/or a treatment using plasma only on the surface of the microbumps **18** in S**26**. The surface activating process may be performed also on the microbumps **19**.

The LD element **20** is mounted in S**27** like in S**17** in FIG. **2** and, after that, a resin **70** for bonding is applied on the microbumps **19** (refer to FIG. **11**A). As the resin **70** for bonding, a thermosetting resin, a UV curable resin, or the like for optical parts can be used.

Subsequently, the PPLN element **30** is aligned and mounted with heat on the resin **70** for bonding (S**29**) (refer to FIG. **11**B). The aligning and mounting method in S**29** is the same as that in S**18** in FIG. **2** and in FIG. **5**B. Therefore, the controller **101** preliminarily considers the elastic return amount of the microbumps **19** and, after the output voltage V from the detector **102** becomes the maximum value (refer to the point D), further applies a predetermined load amount (F: 200(N)) to the PPLN element **30**. That is, the controller **101** further applies a predetermined load so that the incident position **31** of the PPLN element **30** is pushed in to a position which is further deeply pressed from the light emission center **21** of the LD element **20** only by the distance W**3** shown in FIG. **11**B. However, in the aligning and mounting with heat, heating is performed to harden the resin **70** for bonding in a state where the load is further applied.

When the load is released, the incident position **31** of the PPLN element **30** returns to the position where it most-efficiently optically couples to the light emission center **21** of the LD element **20** by elastic return (refer to FIG. **11**C). After that, the series of processes are finished.

With reference to FIG. **10** and FIGS. **11**A to **11**C, bonding between the PPLN element **30** and the silicon substrate **10** using the resin **70** for bonding has been described. The LD element **20** and the silicon substrate **10** may be bonded by using the resin **70** for bonding. In the case where it is necessary to make the LD element **20** and the silicon substrate **10** conducted via the microbumps **18**, it is sufficient to make the resin **70** for bonding penetrate the microbumps **18**. Further, in the case where it is necessary to make the LD element **20** and the silicon substrate **10** conducted by an adhesive, it is sufficient to bond the LD element **20** and the silicon substrate **10** by using a conductive adhesive.

Also in the case of bonding the LD element **20** or the PPLN element **30** and the silicon substrate **10** by using an adhesive, as described with reference to FIG. **8**, in the aligning and mounting process (S**18** in FIG. **2**), only the aligning and mounting device **103** may be used without using the controller **101**, the detector **102**, and the driver **104**.

With reference to FIGS. **12** to **14**, bonding of the sub-substrate **40**, in the processes of manufacturing the semiconductor laser module **1** as an example of the optical module will be described. FIG. **12** is a diagram for explaining bonding

between the substrate **10** and the sub-substrate **40**. FIGS. **13**A and **13**B are diagrams illustrating the positional relationship between the PPLN element **30** and the fiber **50**. FIG. **14** is a diagram for explaining aligning and mounting of the sub-substrate **40**.

As shown in FIG. **12**, a rectangular groove **51** is formed in the sub-substrate **40**, and a front-end part **58** of the optical fiber **50** is fit in the rectangular groove **51** and fixed by an adhesive **57**. It is also possible to form a V-shaped groove in place of the rectangular groove **51** in the sub-substrate **40** and fit and fix the front-end part **58** of the optical fiber **50** in the V-shaped groove. Metal thin films **54** and alignment marks **56** are provided in a bonding face of the sub-substrate **40**. In parts corresponding to the sub-substrate **40** in the silicon substrate **10**, a fiber escape groove **52**, microbumps **53**, and alignment marks **55** are provided.

The sub-substrate **40** is mounted on the silicon substrate **10** by the aligning and mounting device **103** as will be described later. When the sub-substrate **40** is mounted, positions are roughly determined by the alignment marks **55** and alignment marks **56**. After that, while detecting an output from the optical fiber **50** by the detector **102**, the positions in the X-axis direction, Y-axis direction, and Z-axis direction are determined in the submicron order, and the sub-substrate **40** is bonded on the silicon substrate **10**. The microbumps **53** formed on the joint face of the sub-substrate **40** and the silicon substrate **10** are subjected to the plasma cleaning process so that the surface is activated and, after that, bonded by a load applied from the aligning and mounting device **103**. The microbumps **53** made of gold formed on the silicon substrate **10** are formed on the silicon substrate **10** by a method similar to the above-described method of forming the microbumps **18** and **19**.

FIG. **13**A is a cross section taken along line B-B' in FIG. **1**A. As illustrated in FIG. **13**A, the optical fiber **50** fixed in the rectangular groove **51** in the sub-substrate **40** by an adhesive **57** can move in the fiber escape groove **52** provided in the silicon substrate **10** by moving sub-substrate **40** in the X-axis and Y-axis directions by the aligning and mounting device **103**. That is, the position adjustment in the X-axis and Y-axis directions can be performed within the range of the width W4 of the fiber escape groove **52**. In FIG. **13**A, the microbumps **53** and the like are not shown.

FIG. **13**B is a cross section taken along line C-C' in FIG. **1**A. As shown in FIG. **13**B, the front-end part **58** of the optical fiber **50** fixed in the sub-substrate **40** is optically coupled to the outgoing center **32** of the PPLN element **30** with high precision and receives a wavelength-converted green laser beam having a wavelength of 532 nm which is output from the outgoing center **32** of the PPLN element **30**. The green laser beam having a wavelength of 532 nm received by the front-end part **58** of the optical fiber **50** propagates through the optical fiber **50**. Although the microbumps **53** and so one are not shown in FIG. **13**B, the alignment of the outgoing center **32** of the PPLN element and the front-end part **58** of the optical fiber **50** in the Z direction is controlled by the microbumps **53**.

With reference to FIG. **14**, aligning and mounting of the sub-substrate **40** will be described. The example of FIG. **5**B (S**18** in FIG. **2**) relates to the aligning and mounting of the PPLN element **30**. In FIG. **14**, by a similar method, the sub-substrate **40** is aligned and mounted so that the outgoing center **32** of the PPLN element **30** and the front-end part **58** of the optical fiber **50** are optically coupled with high precision. It is assumed that, prior to the aligning and mounting of FIG. **14**, the surface of the metal thin film **54** on the joint face side of the sub-substrate **40** and the microbumps **53** on the silicon substrate **10** are subjected to the plasma cleaning process.

The aligning and mounting in FIG. **14** is performed by using the aligning and mounting device **100** in a manner similar to the case of FIG. **5**B. The controller **101** controls the driver **104** to drive the LD element **20** and make the laser beam enter the PPLN element **30**, and the intensity of a laser beam emitted from the PPLN element **30** and transmitted through the optical fiber **50** is detected by the detector **102**.

First, the controller **101** controls the aligning and mounting device **103** while monitoring the output voltage V detected by the detector **102** and, while moving the sub-substrate **40** in the X-axis and Y-axis directions, determines the position where the output voltage V is the highest (first stage). As described above, since the optical fiber **50** can move in the range of the width W4 in the optical fiber escape groove **52**, the aligning and mounting device **103** moves the sub-substrate **40** in the X-axis and Y-axis directions in this range.

Next, the controller **101** controls the aligning and mounting device **103** and disposes the sub-substrate **40** on the microbumps **53** in the position where the output voltage V is the highest in the first stage.

While monitoring the output voltage V detected by the detector **102**, the controller **101** controls the aligning and mounting device **103** to control the load applied to the sub-substrate **40** and to position the sub-substrate **40** in the Z-axis direction (second stage). After the output voltage V from the detector **102** becomes the maximum value, the controller **101** further applies a predetermined load amount and, then, releases the load. A predetermined load is further applied so that the front-end part **58** of the optical fiber **50** fixed in the sub-substrate **40** is in the position which is further deeply pressed from the outgoing center **32** of the PPLN element **30** only by predetermined distance. After that, by releasing the load, the front-end part **58** of the optical fiber **50** fixed to the sub-substrate **40** returns to the position where it is optically coupled to the outgoing center **32** of the PPLN element **30** most efficiently by elastic return. The above point is based on the theory similar to the aligning and mounting for optically coupling the PPLN element **30** and the LD element **20** described with reference to FIGS. **5**A to **5**C to FIG. **7**. As described above, the sub-substrate **40** is positioned in the X-axis and Y-axis directions in the first stage and is positioned in the z-axis direction in the second stage.

In the method of bonding the sub-substrate **40** described with reference to FIGS. **12** to **14**, as explained with reference to FIG. **8**, only application of a predetermined load may be performed using only the aligning and mounting device **103** without using the controller **101**, the detector **102**, and the driver **104** in the aligning and mounting process (FIG. **14**). In the method of bonding the sub-substrate **40** described with reference to FIGS. **12** to **14**, the sub-substrate **40** may be bonded to the silicon substrate **10** by using microbumps similar to the different microbumps **18'** and **19'** shown in FIG. **9**. In the method of bonding the sub-substrate **40** described with reference to FIGS. **12** to **14**, as explained with reference to FIG. **10** and FIGS. **11**A to **11**C, the sub-substrate **40** may be bonded to the silicon substrate **10** by using an adhesive.

In the foregoing embodiment, as examples of the bonding bumps, the microbumps **18**, **19**, and **53** each having a cylindrical projection and made of Au (refer to FIG. **4**C) and the microbumps **18'** and **19'** each having a truncated cone shape and made of Au (refer to FIG. **9**) have been described. Other bonding bumps may be used as long as they are made of metal and have a shape formed with high precision. The conditions requested for the bonding bumps are that bumps have a material and a shape by which a deformation amount in the case of

applying a predetermined load and an elastic return amount in the case of releasing a predetermined load which is applied are always almost constant.

In the above example, in the optical module **1**, the sub-substrate **40** to which the LD element **20**, the PPLN element **30**, and the optical fiber **50** are fixed is bonded to the silicon substrate **10** by surface-activation bonding using the microbumps. Alternately, the sub-substrate **40** to which only the LD element **20** and the PPLN element **30** or the PPLN element **30** and the optical fiber **50** are fixed may be bonded to the silicon substrate **10** by surface-activation bonding using the microbumps so that optical coupling is carried out excellently.

What is claimed is:

1. A method of manufacturing an optical module including a first optical device and a second optical device bonded on a substrate, comprising the steps of:

forming bonding bumps made of metal on the substrate;
bonding the first optical device on the substrate; and
bonding the second optical device on the substrate through the bonding bumps,
wherein the step of bonding the second optical device comprise the steps of:
detecting a first load where the first optical device and the second optical device are optically coupled most efficiently by using a photodetector for detecting light emitted from the first optical device via the second optical device while increasing a load applied to the second optical device;
obtaining a second load which is larger than the first load and causes the second optical device to a first position where the first optical device and the second optical device are optically coupled most efficiently after releasing said second load in accordance with the result of the detection; and
applying the second load to the second optical device. and
wherein the bonding bumps are made of Au, and said second optical device goes to a second position which is lower than said first position by applying said second load and returns up to said first position after releasing said second load.

2. The method of manufacturing an optical module according to claim **1**, wherein the second optical device is bonded on the substrate through the bonding bumps by surface activated bonding.

3. The method of manufacturing an optical module according to claim **1**, wherein the second optical device is bonded on the substrate by an adhesive.

4. The method of manufacturing an optical module according to claim **1**, wherein the bonding bumps include a plurality of projections.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,214,446 B2
APPLICATION NO. : 13/422656
DATED : December 15, 2015
INVENTOR(S) : Kaoru Yoda

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the claims

Claim 1, Col. 11, line 24, "comprise" should read --comprises--.

Claim 1, Col. 12, lines 10-11, "device. and" should read --device, and--.

Signed and Sealed this
Nineteenth Day of July, 2016

Michelle K. Lee
Director of the United States Patent and Trademark Office